

THE IMPACT OF DESIGN TO COST  
ON NAVAL SHIP DESIGN

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THE IMPACT OF DESIGN TO COST  
ON NAVAL SHIP DESIGN

by

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# THE IMPACT OF DESIGN-TO-COST ON NAVAL SHIP DESIGN

by Michael Nickelsburg

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## ABSTRACT

The impact of design-to-cost on naval ship design as implemented in the design of the Patrol Frigate is examined in two areas: the management or control of constrained design parameters, and the resulting ship design produced under the constraints of cost, manning, and displacement.

The naval ship design process is reviewed, discussing the changes in design methodology brought about by the Laird/Packard/Zumwalt weapon systems acquisition philosophies. The management of the Patrol Frigate design is discussed, concentrating on the effort to control ship size. The evolution of the Patrol Frigate is followed from the determination of the requirements for a new ship through the design effort conducted by the Naval Ship Engineering Center.

The naval ship design aspects of the Patrol Frigate are examined. The effort to keep ship displacement below the given goal is examined. The Patrol Frigate is compared with similar U.S. Navy ships to determine the differences between the PF and other recent ship designs. The austerity decisions are quantified and analyzed to determine the effect of these decisions on the PF design.

Conclusions are drawn as to the effectiveness of design constraints in reaching a displacement goal, the management of the constraints, the role of the ship designer and the ship customer, the Chief of Naval Operations, and the future of design-to-cost.

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## CHAPTER I

### INTRODUCTION AND BACKGROUND

#### 1.1 Introduction

The Patrol Frigate (PF) is an escort destroyer, designed to provide protection for Navy replenishment and amphibious ships, and military and merchant cargo ships and tankers. Although the PF is a multipurpose ship, the ship's design emphasizes defense against enemy aircraft and missile attacks, with a secondary anti-submarine capability.(29)

(NOTE: Numbers refer to references at the end of this thesis.)

The studies leading to the design of this ship were initiated in September 1970. The ship design continued from 1970 through 1975. The keel for the lead ship in the class was laid in early 1975, and the first ship is to be delivered in 1977. This ship was called the Patrol Escort through the ship conceptual design phase, the Patrol Frigate (PF109 class) through most of the detail design phase, and is now known as the Guided Missile Frigate (FFG-7 class). For consistency the term Patrol Frigate (PF) is used throughout this paper.

The Patrol Frigate is the first Navy ship design to be initiated under the administration of Laird and Packard in the Defense Department and Admiral E. Zumwalt as Chief of Naval Operations. Under the guidance of these men, the design-to-cost philosophy applied to naval ships evolved



parallel to the Patrol Frigate design and acquisition. Leopold, Jons, and Drewry describe this philosophy in their paper, "Design-to-Cost of Naval Ships".(8)

This paper examines the design-to-cost philosophy as implemented in the design of the Patrol Frigate with the use of design constraints on cost, manning, and displacement. The purpose of design constraints can be shown by quoting the PF program objectives during the conceptual phase:

"The major objectives of the Patrol Escort Program are to define ship characteristics and performance requirements, to minimize ship size and cost consistent with mission requirements, to estimate total program costs with accuracy, and to produce the patrol escort ships at or below the program cost estimates."(47)

This purpose was rephrased in the Patrol Frigate Ship acquisition plan as:

"The major objectives of the PF program are to minimize ship size and cost consistent with mission requirements, to estimate total program costs with accuracy and realism, and to produce the PF ships at or below program cost estimates."(49)

The primary objective of the Patrol Frigate program is to reduce follow ship acquisition cost; however, most engineers and naval architects involved in naval ship design have had little involvement in the cost process and would be unable to design effectively to a cost budget. Therefore, other, more readily understood parameters, such as manning, space, and weight, are used as design constraints. Thus a more accurate term for describing design-to-cost is constrained ship design. In this thesis constrained ship design is used synonymously with the more common term, design-to-cost.



This thesis examines the effect of constraints on the design of the Patrol Frigate in order to answer the question, "What is the impact of constraint on the Patrol Frigate?"

This question is addressed in two major areas: the management or control of the constrained parameters, and the resulting ship design produced under the constraints of cost, manning, and displacement.

Chapter I provides background material, reviewing the development of the design-to-cost philosophy to determine how this philosophy differs from that of other ship designs. Chapter II discusses the management of naval ship design under the design-to-cost philosophy. The naval ship design process is reviewed, including the changes in design methodology brought about by the Laird/Packard/Zumwalt weapon system acquisition philosophies. The management of the Patrol Frigate design is discussed, concentrating on the efforts to control ship size. The evolution of PF is followed from the determination of the requirements of a new ship through the design effort conducted by the Naval Ship Engineering Center (NAVSEC).

Chapter III examines the naval ship design aspects of the Patrol Frigate. The effort to keep weight below the given goal is examined, and the decisions to keep the weight and cost of the PF low are presented. The Patrol Frigate is compared with similar U.S. Navy ships to see



how the PF is different from other recent designs. The austerity decisions are quantified to determine the effect of these decisions on the PF design. Conclusions are drawn as to the effectiveness of design-to-cost and the role of the designer and the customer, the Chief of Naval Operations. Chapter V briefly outlines the progress of design-to-cost since the PF and the prospects for future constrained ship designs.

Although the final judgment on the effect of design-to-cost on the Patrol Frigate will not be known until the ship is built and operated at sea, several conclusions are drawn from the design effort to date.

## 1.2 Background

Historically naval ship design has consisted of the operator providing the design agent with the desired ship characteristics and the design agent optimizing ship mission performance within stated requirements. Cost was considered a dependent variable.

In the MacNamara era of systems analysis, cost was included as a major parameter in the design process. Ship design was based on meeting performance criteria at the lowest life-cycle cost. Life-cycle cost optimization was abandoned early in the Laird/Packard administration for a multitude of reasons. The large cost overruns in weapons system acquisition programs, the inability to predict life-cycle costs accurately, the increased visibility of the







Defense Department budget, the increased criticism of the Defense Department objectives originating in the opposition to the Vietnam War, the increased cost of major weapon systems due to increases in system complexity and the effects of inflation, and the increased demand for Federal funding to solve social problems led to the abandonment of the Total Package Procurement method of defense systems acquisition. (NOTE: Total Package Procurement and other Weapons System Acquisition policies under MacNamara are examined in detail in the Report of the President's Blue Ribbon Defense Panel, July 1970.)

Department of Defense Directive 5000.1 "Acquisition of Major Defense Systems", (21) superceded the Total Package Procurement Directives and provided Defense Department policy and guidance for ship acquisition programs. DOD Directive 5000.1 produced several changes in weapon systems acquisition, including the separation of system development and production efforts, "fly-before-buy" requirements, the reaffirmation of the Development Concept Paper (DCP) and the Defense System Acquisition Review Council (DSARC), and the inclusion of technical risk as a major design consideration. This thesis will discuss one aspect of the acquisition policy established by DOD Directive 5000.1, as set forth in paragraph IV, C.2:(21)



"Cost parameters shall be established which consider the cost of acquisition and ownership; discrete cost elements (eg., unit production cost, operating and support cost) shall be translated into "design to" requirements. System development shall be continuously evaluated against these requirements. Practical tradeoffs shall be made between system capability, cost, and schedule. Traceability of estimates and costing factors, including those for economic escalation, shall be maintained."

The requirements for establishing cost parameters were further defined in SECNAVINST 5000.1 (50) which implemented DOD Directive 5000.1 within the Department of the Navy. The SECNAV Instruction states that: "Cost parameters shall be established to reflect the cost of acquisition and ownership. Ownership costs will include life-cycle costing."

Further definition and guidance in the implementation of the design-to concept was promulgated in NAVMAT P-5242, Joint Design-to-Cost Guide. (27) According to the Joint Design-to-Cost Guide, unit production cost must become a primary design parameter. This policy, of course, is a reversal of the past practice of optimizing total life-cycle cost under the Total Package Procurement method of ship acquisition. The Joint Design-to-Cost Guide cautions against using unit cost as the sole driving consideration in systems acquisition. "Acquisition cost reduction must not be achieved at the expense of increased ownership costs or through the sacrifice of performance essential for mission accomplishment." (27)



Design-to-cost is defined as a process which uses unit cost goals as thresholds for managers and as design parameters for engineers. This cost goal is divided into unit production cost goals by the Program Manager, to be provided to the contractors and in-house managers for the appropriate subsystem. The designated cost goal represents the amount that the government, at some level of the bureaucracy, has decided that it can afford (is willing and able) to pay for a unit of military equipment or major subsystem which meets established and measurable performance requirements. (27)

The design-to-cost concept is aimed at a reduction in cost, rather than a justification of cost after completion of a design to a performance level. This concept requires considerable emphasis in the management of the design effort to maintain costs below the pre-determined level. The Program Manager must be given the flexibility to provide the best possible design which performs the required mission within the established cost goal. Unit production cost must be related to an economic production schedule and the minimum number of essential performance requirements. If the iterative design process cannot achieve the desired cost constraint, then "there must be a willingness to trade off desired performance to achieve the cost goal while assuring that a viable weapons system design is obtained". (27)



The Joint Design-to-Cost Guide requires that other costs be considered in the weapons system acquisition process. Adequate developmental funds must be made available so that system and subsystem redesign can be used when necessary to decrease total production cost. Support hardware and services such as crew training and critical spares, normally included in the production contract, should not be arbitrarily reduced to achieve low unit production costs. Although life-cycle cost should not be sacrificed to meet the unit production cost, schedule, and performance goals, the Joint Design-to-Cost Guide recognizes the difficulty in determining life-cycle cost by stating that "Wherever quantifiable life-cycle cost can be effectively estimated, strong emphasis will be placed upon its inclusion in the acquisition process." (27)

The concept of design-to-cost departs from previous design philosophies in two major areas:

- 1) Acquisition costs (defined in a very narrow sense) and not life cycle costs are optimized.
- 2) Ship design is not performance optimized.  
Performance must be balanced against cost.

As discussed above, the directives which control the acquisition process acknowledge the importance of life-cycle cost, but do not present guidelines for the tradeoff between life-cycle and acquisition cost. Because acquisition cost







is relatively easy to define and is one of the more visible cost quantities, this value is used as the cost goal or constraint. When conflicts occur, other, less visible costs will undoubtedly be sacrificed to maintain the project cost within the stated goal. This reaction is basic to human nature, but can increase the total cost of the ship to the Navy. Increases in the operating and maintenance costs will leave less money available for future ship acquisition projects.

The idea that a ship design does not need to produce a maximum performance vehicle is new with the design-to-cost philosophy. The guidance on cost/performance tradeoffs is vague and can mean whatever is convenient. In the examples quoted above: "There must be a willingness to trade off desired performances to achieve a cost goal," but, "Acquisition cost reduction must not be achieved . . . through the sacrifice of performance essential for mission accomplishment." The Chief of Naval Operations, speaking for the men who must fight in these ships, must decide how much he is willing to pay and how much performance he is willing to give up to reach his cost goal. He must be flexible enough to change his performance and cost goals as the ship is defined during the design process and the desired product is reconciled with the feasible ship design options.



The guidance higher management gives to the Ship Acquisition Manager (SHAPM) is full of philosophy, buzz words, and sweeping generalizations. This guidance is lacking in solid directives as to the methods for control of cost. This thesis examines how part of that philosophy was executed in one ship design, the Patrol Frigate (PF).

The Patrol Frigate is the first Navy ship to be designed under the "design-to-cost" and fly-before-buy" concepts set forth in DOD Directive 5000.1. The PF is the first "low mix" ship to be designed under the new high/low concept of ship acquisition. (This concept is explained in Chapter II.) The majority of the ship requirements and the design and acquisition decisions were based on a system that was not formally promulgated. The first design constraints were formally imposed on the PF design on June 1971, although DOD Directive 5000.1 was not promulgated until July 1971, SECNAVINST 5000.1 was not promulgated until March 1972, and the Joint Design-to-Cost Guide NAVMAT P-5242 was not promulgated until October 1973. Many of the experiences of the Patrol Frigate acquisition were incorporated into these directives. The study of the PF is the study of a system in evolution.



## CHAPTER II

### MANAGEMENT OF NAVAL SHIP DESIGN

This chapter discusses the control of naval ship design from the limited aspect of the control of the design of the ship system. The control of other aspects of the acquisition process, such as the control of concurrent subsystem development, fiscal control of the ship design effort, risk management, and integrated logistics support are not addressed.

The design process, as envisioned for future design-to-cost ships, is presented first to provide a basis for comparison with the PF project. This design methodology has grown out of recent experiences with the "design-to-cost" and "fly-before-buy" philosophies since the promulgation of DOD Directive 5000.1.

The Patrol Frigate design and acquisition has proceeded as a part of the evolution of these philosophies, and this design procedure has relied heavily on the PF experience. The second part of this chapter discusses the control of the design of the Patrol Frigate, from a determination of the requirements of a new ship through the completion of the contract design.



## 2.1 Naval Ship Design Process (20,32,52,60)

A review of the naval ship design process is necessary in order to be able to discuss the PF ship design.

Ship design is an iterative process, usually described in the literature by reference to the overworked ship design spiral. In each design phase the engineering studies are repeated to a greater level of detail, assumptions are verified or corrected, and a new, more complete baseline is established.

Naval ship design is divided into five distinct stages, which can be described in very simplified terms as:

- 1) Feasibility studies--Performance/cost tradeoffs
- 2) Conceptual design--Definition of ship system, including sizing of the platform
- 3) Preliminary design--Subsystem tradeoff and engineering definition of ship
- 4) Contract design--Validation of design and preparation of contracting specifications
- 5) Detail design--Construction drawings and procurement specifications for contractor furnished equipment (CFE)

The sequence of these five phases is shown graphically in Figure 2.1. The terminology used in part of the Patrol Frigate design is different from that described here and is also shown in Figure 2.1. Figure 2.2 shows these design phases in more detail.

Feasibility studies are performed to establish cost vs. performance tradeoffs and to identify these tradeoffs in a consistent manner. Ship feasibility studies start with a





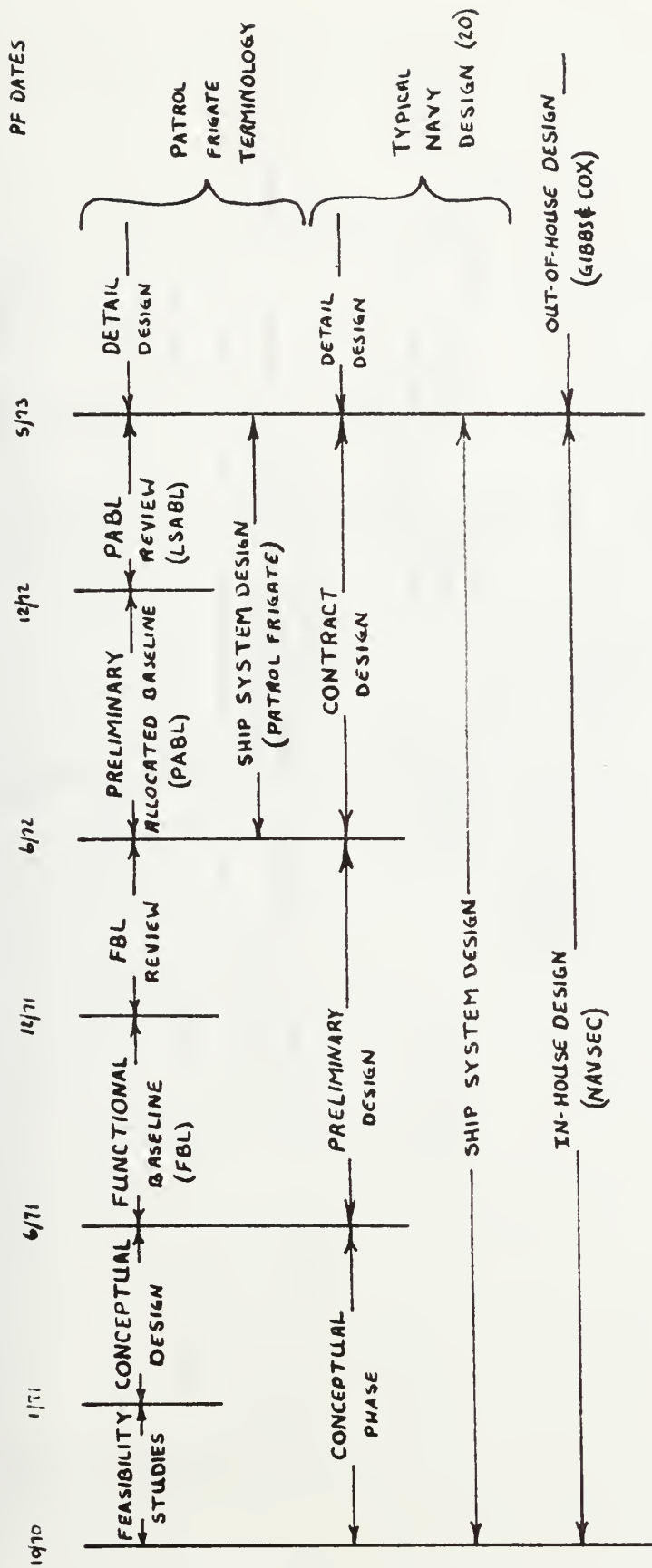


Figure 2.1. Patrol Frigate Ship Design Phases



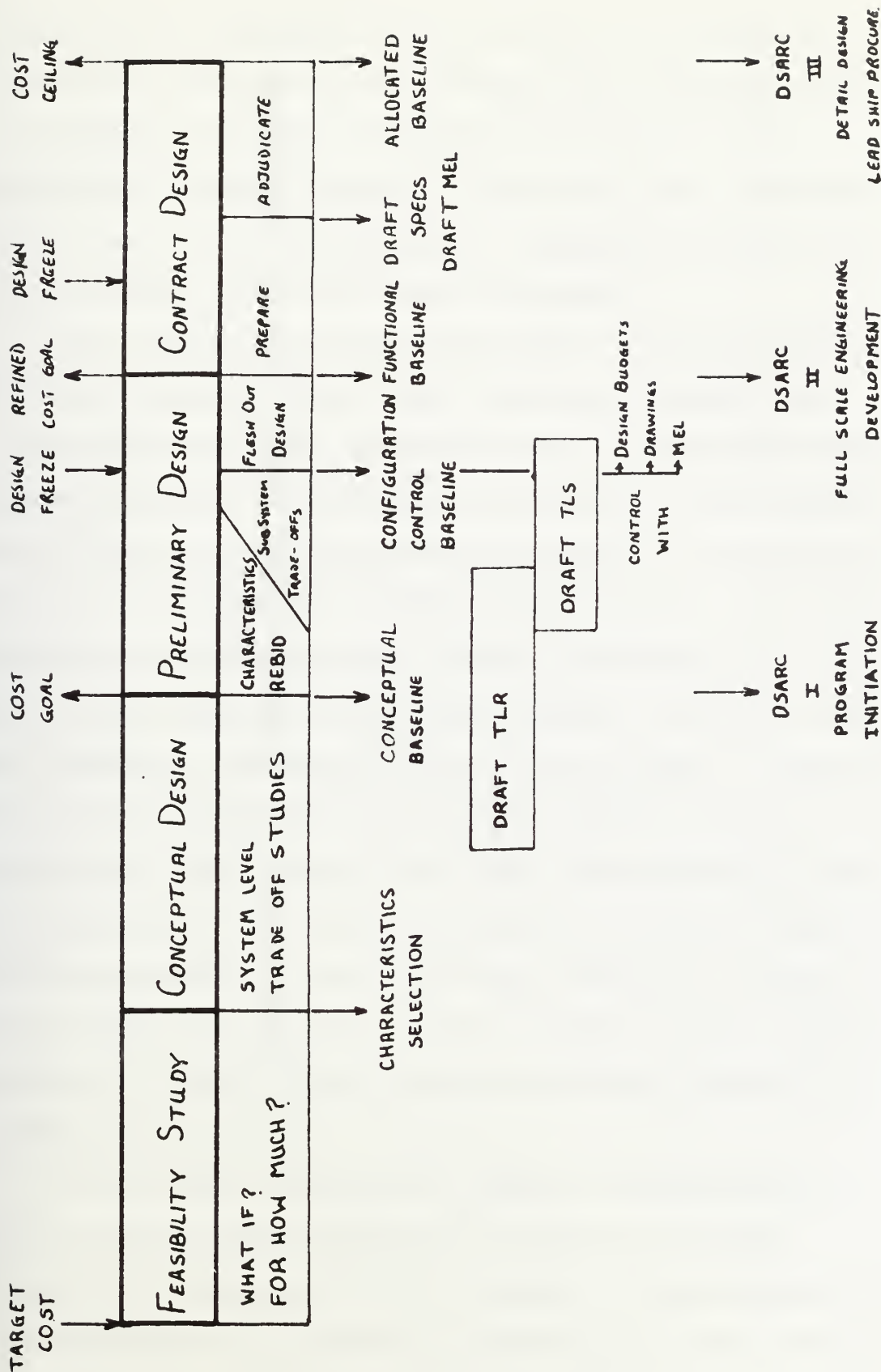


Figure 2.2. Design-to-Cost of Naval Ships (as it should be) (52)



target cost. The target cost is based on a subjective analysis of the type of ship desired, the number of ships expected in the class, and what price ship will be acceptable to higher authority within the Navy, Department of Defense, and to the Congress. Feasibility studies ask the questions, "What if?" and "How much?".

For conventional ship types there is a broad technical base upon which to draw. This technical base has been incorporated into Ship Synthesis Models and computer ship design programs, such as DD-07 for destroyer type ships. Ship design alternatives can be constructed to determine the effect of changes in speed, range, payload, and other performance characteristics. Using a Synthesis Model, 50 to 300 ship designs are usually evaluated. Marginal costs are frequently calculated to allow the customer to see the effects of changes in ship design parameters. For a conventional ship type, size, cost, and payload are the real questions, not the feasibility of the ship. Where ship requirements are well defined, feasibility studies can be done to within 5% accuracy in ship weight; however, absolute accuracy is not required during the feasibility studies.(32)

At the end of feasibility studies a whole range of ship synthesis model designs with Class E or F cost estimates is presented to the customer. (Cost estimating classifications are defined in Appendix B.) The Chief of



Naval Operations selects that combination of cost and performance that best meets his needs and his resources, and these characteristics are used as a basis for the conceptual design phase.

The purpose of conceptual design is to determine an absolute size and cost of the desired ship. Ship geometry is established, main propulsion machinery is selected, and an electrical power analysis is performed. Principal weapon systems are located to reduce arrangement problems, but combat system integration is not performed. Space and weight budgets are established. Platform subsystem trade-offs are not performed; standard approaches to subsystem design are assumed. Any major technical risks associated with the design must be resolved in order to produce valid cost and weight estimates.

The draft Top Level Requirements (TLR) is developed by OPNAV and the SHAPM. The TLR is a broad qualitative description of the ship, which outlines the minimum essential performance characteristics acceptable to the customer (CNO).

The total ship design, called the conceptual baseline, is reviewed to ensure that the design produces a balanced ship. With the development of a baseline design on which to make initial cost estimates, a cost goal is set for preliminary design.





The conceptual baseline should have a Class D cost estimate, which becomes the basis for the CNO cost goal, a firm price which should not be exceeded without CNO approval. In the PF, the conceptual design effort included many feasibility studies, and the conceptual baseline cost estimate was a Class F or "ballpark" estimate.

It is important to have an accurate estimate of ship size at the completion of conceptual design in a design-to-cost ship. Initial cost estimates are based on displacement, weapon systems (payload), and propulsion machinery. If the estimated cost of the ship at the end of the conceptual study is significantly different from the original target cost, the feasibility and weapons effectiveness studies should be re-evaluated to determine if the performance features can be changed. The conceptual baseline is used as a basis for the preliminary design cost goal (or, in the PF, the cost constraint). If the conceptual baseline produces an unreasonably low cost target, the ship designers will have difficulty in producing a ship within the stated goals, as in the PF. If the conceptual baseline produces too high an estimate, the design team may not design to the lowest possible cost and weight, as in the Sea Control Ship. (52)

The conceptual design phase is the single most important phase in the design-to-cost cycle. (46) The decisions which have the greatest impact on cost are made at this time. The



most significant decisions include selection of ship's speed and endurance, which establishes the propulsion plant requirements, and selection of the ship's weapons and sensors, which establishes combat systems and combat systems support requirements. The basic problem is maintaining restraint in the establishment of mission, ship performance, and payload requirements, so that further design development can reasonably be expected to produce a viable ship within the given cost constraints. The impact of mission and payload requirements on the ship design must be kept continually in mind to ensure that the minimum performance requirements are established.

At the completion of conceptual design, two outputs should have been produced: 1) the best compromise between speed, range, and payload vs. cost from feasibility studies and companion military effectiveness studies; 2) absolute size and cost of the platform. These design parameters should only be changed through subsystem tradeoffs in subsequent phases of ship design or through the process of combat system integration.

At the completion of conceptual design, the ship proposal is presented to the DSARC, the Defense Systems Acquisition Review Council. DSARC membership consists of the Director, Defense Research and Engineering, the Assistant Secretaries of Defense (Comptroller), (Installation and Logistics), (Intelligence), and (Programs Analysis



and Evaluation), and the Director, Telecommunications and Command and Control Systems. The program is presented to DSARC in the Development Concept Paper (DCP), and DSARC recommends continuation or cancellation of the program to the Secretary of Defense. The purpose of this presentation, known as DSARC I, is to obtain approval for program initiation or the commencement of preliminary design.

The purpose of preliminary design is to develop the ship design to the subsystem level. The given characteristics are re-evaluated, subsystem trade-offs are conducted, and a functional baseline (FBL) is completed. Considerable detailed engineering takes place during this phase of ship design.

All platform subsystems are sized, based on the actual ship support they must provide, and subsystem trade-offs may produce a change in ship's size, weight, and cost. Much of the subsystem development that was previously done during contract design is now part of preliminary design. It is necessary to reach this level of detail earlier in the ship design in order to carry out meaningful subsystem tradeoff studies. Preliminary design results in a complete engineering definition of the ship.

Effective cost visibility is lost during most of the preliminary design phase.(20) There is a weight accounting budget for individual systems, but the design as a whole ship is not firm until after the design freeze during the



latter part of preliminary design. System tradeoff studies are conducted on the basis of cost deltas, marginal cost factors which relate follow ship cost changes with changes in manning, weight, and space. In practice this has been less than completely effective. Detailed cost data is not readily available, and many engineers are reluctant to deal in terms of cost figures of any kind.(20)

Configuration control is the key to establishing and maintaining effective control over a ship design. To date NAVSEC has applied formal configuration control procedures on four ship design projects, the Patrol Frigate (PF), Sea Control Ship (SCS), Anti-Air Warfare Destroyer (DG-AEGIS), and Fleet Oiler (AO-177 class). This section outlines configuration control as it should be carried out, based on the experiences of these four designs.

Configuration control should be based on two separate categories of design parameters, those which are controlled by the design manager and those which are used to indicate the status of the design, recording the configuration after changes have been incorporated into the design. The ship design manager should institute control procedures in those areas where they will be most effective: space, manning, and a controlled equipment list. Other areas, such as weight, cost, master equipment lists, electrical power, and combat system block diagrams, should be included in the area of configuration status. This formal delineation between







control documentation and status documentation has not been used in past designs, but some of the change control documentation has fallen into the status category because of the undesirability or impracticality of controlling these design parameters.(60) A NAVSEC handbook, "Design Configuration Control Requirements and Procedures", issued in February 1975, describes in detail the two tier configuration control and recommends procedures for implementation of configuration control procedures.(32)

About two-thirds of the way through preliminary design, the ship design is frozen, so that a complete baseline may be prepared. The remainder of preliminary design is used to prepare a functional baseline and Top Level Requirements for presentation to DSARC II. A refined cost goal can now be determined, using the results of system and subsystem tradeoff studies.

At the end of preliminary design, the functional baseline is used to produce a Class C estimate. At this point the majority of the engineering features of the ship have been designed so that the potential for additional major cost reduction is negligible without undertaking major subsystem or equipment modifications.

Top level requirements are completed during preliminary design and should be signed by the Chief of Naval Material and the Chief of Naval Operations prior to presentation of the program to DSARC II. The draft Top Level Specification



(TLS) is started at this time. The TLS, issued by the NAVSHIPS Ship Acquisition Project Manager (SHAPM), presents the quantitative performance requirements for the ship. Navy Ship Acquisition programs have not used the TLR/TLS documents in the manner in which they were intended (See Section V).

At the completion of Preliminary Design, the Navy must return to a second DSARC to get permission to continue with full-scale engineering development. For the ship design this means initiation of contract design after cost differences between CNO goal and the functional baseline estimates are reconciled. Again there is little cost visibility in contract design, except where major change proposals are evaluated. Formal change control procedures are used to minimize cost and weight growth. Since much of the detailed engineering work is done in preliminary design, contract design primarily consists of translating the functional baseline into a set of contract specifications.

These specifications must define the ship to the level of detail necessary for a prospective shipbuilder to be able to bid for the construction contract for the ship. The primary output of contract design is the Ship Specification, contract drawings, and contract guidance drawings. All design work carried out in previous phases is validated and developed to a greater level of detail. Reading sessions are used to review the ship specifications



to ensure their completeness and to avoid contradictions within the contract documents. Very few changes to the ship design should occur during contract design. At the end of contract design, a Class A or B cost estimate is produced with the allocated baseline. This cost estimate becomes the cost ceiling for detail design and construction.

Contract design ends the Navy's direct participation in the ship design. A contract is awarded to a lead shipyard to conduct detail design. The lead shipyard or its design agent carries out the detail design under the contractual arrangements enforced by the SHAPM. Detail design is used to convert the Contract Design Package into working drawings for ship construction and into procurement specifications for Contractor Furnished Equipment and Material. The control of the ship design in this stage of the acquisition cycle is beyond the scope of this thesis.

## 2.2 The Patrol Frigate Design

Control of the Patrol Frigate design is presented in three parts. First the requirements for a new ship were determined, and a ship type, size, and mission were proposed. After confirming the feasibility of this ship design, constraints were levied by the Chief of Naval Operations (CNO). Then the ship design effort was conducted by the Naval Ship Engineering Center (NAVSEC). This discussion of the control of the ship design is concentrated on the effort to control ship size and cost in order to complete the ship design within the desired constraints.



### 2.2.1 Determination of Requirements (15,62)

The United States' long-range military objectives are set by the President with the assistance of his primary advisors, Cabinet members, and the National Security Council. The Secretary of Defense and his staff translate national objectives into the missions and tasks of the separate armed services as set forth in the DPPG, Defense Policy and Programming Guide. The Chief of Naval Operations, through his staff, OPNAV, determines the force levels and force mix required to carry out the missions assigned to the Navy.

In 1970 it was realized that there was a need for a large number of escort ships to replace the World War Two vintage destroyers which were in poor material condition and contained obsolete equipment. The projected force levels fell below the numbers that will be required in the early 1980's.

Studies were conducted to determine the relationship between the number of ships that could be built and the collective force effectiveness for a fixed total cost of non-carrier capable escort ships.(15) Hull sizes from 1500 tons to 7000 tons were selected, typical armaments were determined for each hull size, and ship costs were computed. The force of escort ships ranged from a few very effective and very expensive ships which cannot protect enough areas to be a significant improvement in force effectiveness, to many small inexpensive ships which do







not carry enough armament to provide significantly increased protection to the fleet.

Operating scenarios analyzed combat situations with the new ships in company with a mixed force of existing ships. A displacement force effectiveness plot was developed which showed a broad maximum effectiveness in the 3000/3500 ton range. (Figure 2.3) This size ship was priced in the 45-50 million dollar range.

At this time the high-low concept of Naval force mixture was being developed. The high mix ships are fully capable ships which can operate with the offensive strike forces. These high cost ships can only be purchased in limited numbers and include the CVAN's, DLGN's (now CGN's) and nuclear submarines. A large number of less capable, relatively austere low-mix ships can then be built to carry out the other missions of the Navy.

In September 1970, Admiral Zumwalt directed that studies begin on a new escort in the 50 million dollar price range, with a displacement of about 3200 tons. Initial feasibility studies indicated that this was possible, and conceptual design commenced in January 1971.

#### 2.2.2 Conceptual Design (47)

Conceptual design consisted of tradeoff studies between mission requirements and ship weapons and propulsion systems. During this phase of the ship design process, the Office of the Chief of Naval Operations (OPNAV), represented by



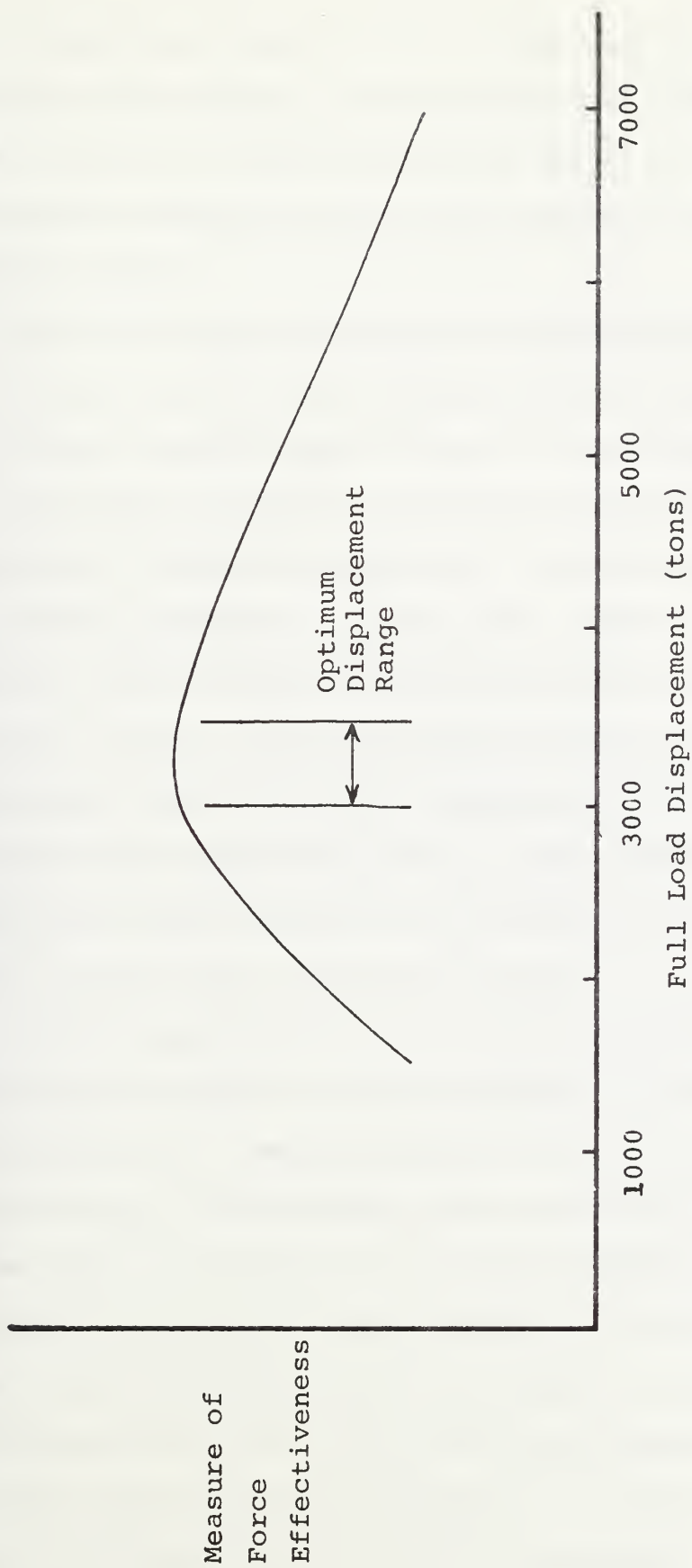


Figure 2.3. Collective Force Effectiveness vs. Ship Size for a New Class of Escorts  
(15)



RADM Frank Price, would not set definitive requirements. RADM Price had frequent meetings with the SHAPM staff to present "what-if" questions and to review the possible alternatives derived manually and through the NAVSEC ship synthesis model.

Two ship configurations were developed during conceptual design, one for anti-submarine warfare (ASW) and one for anti-air warfare (AAW), since it was assumed that both ship types were required to perform economically the missions and tasks envisioned for the Patrol Escort. As the studies proceeded, a common ship with two versions differing only in combat systems evolved as the best candidate design. Several hundred alternative ship configurations were developed, including conversion or redesign of DE1052 class and USCG Hamilton class ships. During conceptual design, emphasis was placed on the selection of weapons suits, and propulsion system.

At the completion of the conceptual studies, several ship design alternatives were presented to the Chief of Naval Operations. Admiral Zumwalt selected one set of ship characteristics and directed that preliminary design start on that ship, primarily an AAW ship with ASW capability. The concept of a single hull design with two separate combat system configurations was dropped at this time. It was estimated that this ship would displace almost 3700 tons and cost almost 50 million dollars. At this point Admiral Zumwalt selected the first design constraints.



### 2.2.3 Constraints (55,57)

The design constraints were first imposed at the end of conceptual design. Admiral Zumwalt wanted to ensure that the PF did not experience the growth seen in other weapons acquisition projects. A cost of \$45-50 million per ship was estimated at the end of conceptual design. The CNO wanted to put as much "incentive" as possible into maintaining the low cost of the follow ships, and therefore he selected \$45 million per follow ship as the cost constraint.

The PF displacement constraint evolved from Admiral Zumwalt's experience with the growth of the DX (DD963) design, beginning with his involvement in the conceptual studies of the DX. When he returned to Washington as CNO following his tour of duty in Vietnam, he was dismayed to find that the displacement of the DD-963 had grown by about 1000 tons. (NOTE: Exact design displacement of the DD-963 at any point in time is difficult to determine because of the numerous configurations of this ship design. The open literature is very confusing on this point.) The displacement constraint on the PF (and later on the DG-AEGIS) was his method of ensuring that the same type of growth did not happen to the new ships.

The manning constraint was imposed upon the PF design as an afterthought. (57) A chart showing the projected manning distribution was used to show the sensitivity of





the ship's crew to proposed system options in a briefing to Admiral Zumwalt. The purpose of this briefing was to obtain a decision on cost reduction alternatives. Admiral Zumwalt decided that a reduction in ship manning could be made without significantly reducing ship capabilities, so he told the SHAPM to reduce ship manpower requirements. The CNO imposed a limit of 185 accommodations on the ship design.

A manning reduction has the advantage of reducing both acquisition cost and life cycle cost of the ship. A reduction in accommodations reduces the space and weight required for crew berthing, messing, and recreation, and has the secondary effect of reducing the space and weight of all crew-related ship systems, provisions, laundry, personnel services, electric power, etc. Manpower costs are estimated to consume 55% of the life cycle cost of a ship, so any significant reduction in manning will also reduce life cycle costs.(1)

Although a reduction in manpower reduces cost and displacement directly, in some ways this reduction works against the other constraints. A decrease in ship manning requires automation of many ship functions; but automated equipment costs money and usually carries a greater technical risk than non-automated equipment. The lower reliability of automated equipment and the decrease in maintenance



personnel will result in a sacrifice in ship reliability unless these factors are offset by an increased redundancy in equipment, requiring additional cost and weight.

The setting of design constraints influences the entire design process and therefore should be done in a rational manner, based on a technical assessment of the entire problem. The operating forces became very much involved in technical decisions concerning the ship design. RADM Price represented OPNAV in the design of the Patrol Frigate to an extent never before seen in ship design. The Navy's design branch (NAVSEC) no longer makes many of the design decisions. In many cases their role is to surface viable alternatives for consideration by the customer (OPNAV).

(55) Admiral Rickover has critically emphasized the differentiation between the role of the line officer and the technical specialist. He points out that "(The line officer) has become deeply involved in making decisions on technical matters for which his training has not qualified him. Instead of deciding what he needs, he is now often deciding how his needs shall be met." (15)

The criticism in this thesis is not directed specifically at Admiral Price, as the author is not familiar with the Admiral's technical qualifications, but at the precedent that he is setting in the relationship between the operating forces and the design staff.



#### 2.2.4 Design Controls

Sections 2.2.1, 2.2.2, and 2.2.3 have shown how the design constraints of cost, displacement, and manning were developed. These requirements must then be imposed on the ship design. This section discusses how cost and ship configuration were controlled on the Patrol Frigate design by the Navy's ship design agent, the Naval Ship Engineering Center (NAVSEC).

##### 2.2.4.1 Cost Control

Design-to-cost is a misnomer in the PF and other ship designs. Costs are used as one design parameter in system and subsystem tradeoff studies, but total ship cost is only known at specific design freeze points. Cost control is hampered by a lack of design detail in the early stages of ship design. Many cost estimates are approximations based on system weights and educated guesses as to the cost of equipment. The subsystem designers and engineers have not developed the tools for design-to-cost. The final design may be influenced by a desire to minimize cost, weight, space, or manning, but this is not design-to-cost.

A simple cost program, relying on "one-digit" weights, was developed by NAVSEC for use in the PF Concept Exploration to determine cost estimates for design alternatives.

During the FBL and PABL stages of ship design, cost changes to a design baseline were used to evaluate design



tradeoffs. Marginal cost factors were developed for pounds of displacement, square feet of deck area, and required manning. These factors were used to calculate cost deltas, increases or decreases in follow ship costs. J.J. Sejd describes the marginal cost concept in his article in the Naval Engineer's Journal.(18) Also, in certain instances, cost estimates were used to evaluate systems.

A running total ship cost was not maintained during the PF ship design. Cost decisions were made on the basis of the cost deltas, and total follow ship costs were calculated only at certain design milestones. In addition, 30-40 percent of total ship costs were a function of the Combat System, and not under the control of NAVSEC Ship Design Manager.

Ship costs were considered as a design parameter and known to be important, but were not used to monitor the progress of the ship design or to control the ship design. That function fell to the space and weight budgets and the broad area of configuration control.

#### 2.2.4.2 Configuration Control

The design budget is identified as a management tool in the Patrol Escort Concept Exploration Report.(46) The purpose of this budget is to give visibility and accountability to ship subsystems. The budget identifies the demands of subsystems on overall ship size and cost so that the effect of subsystem design on the ship is known and can be adjusted in subsystem tradeoffs.





The quantities of weight, space, vertical center of gravity, electrical power, cooling water, salt water, and high pressure air were to be controlled through the design budget. The budget concept as implemented in the PF was too ambitious and unrealistic, and was not completely successful.(37) The PF design budget was actually used to control weight and usable deck space. The other design factors were controlled by other means or not controlled at all.

Electric power was not controlled because the individual engineers were unable to determine power requirements within the work breakdown structure. Sea water, fresh water, and high pressure gases could not be controlled to the level of detail necessary with the limited available manpower.

Cost was not controlled by the design budget. Cost factors are not known in fine enough detail to be factored into the design early in design process. Total ship cost estimates were computed at NAVSHIPS (now NAVSEA), not by the design team at NAVSEC. NAVSEC developed marginal cost factors using the Ship Synthesis model (DD-07), which were used in making tradeoff decisions.

The use of a weight budget of 3400 tons for the PF was not totally effective as a method for controlling displacement.(37) Prior to the PF design NAVSEC Code 6133, Weight Branch, had handled all of the ship system weight accounting.



System designers were not familiar with the weight breakdown structure, and many were not aware of the actual weights of equipment they were installing. A lack of familiarity with weights hurt the weight control efforts. The original assignment of weights within the 3400 ton budget was arbitrary, not based on a careful analysis of weight distribution in previous ship designs. Consequently some designers were assigned only 25-50% of the weight necessary to complete any design, while others had a weight surplus. Many designers who were unable to design a system within the budget ignored the weight control system, while many designers with excess weight hoarded their surplus. Many engineers did not understand, nor did they properly use the change request processes.(37)

A further problem in weight control was a failure to look at the total ship impact of small changes in subsystem design. Looking at each system by itself can distort the decision-making process, usually in favor of changes in the system, since it is easy to argue that a small change will not affect the ship early in design.

Except for specific trade-off studies, such as 400 Hz motor generators vs. static convertors, ship's service power analysis, sources of auxiliary heat, etc., the Change Control Board concentrated on the arrangement drawings for control of the ship design.



The ability to control the PF ship design adequately was a function of the leadership provided by the project management team in NAVSEC and of the Change Control Board. Significant effort was expended to ensure that as many reasonable alternatives as possible were examined for space and weight savings. Standard design practices and design margins were carefully examined, and those which could not be backed by engineering analysis were reevaluated to reduce total ship weight. This practice produced some problems which resulted in the addition of a fourth diesel generator, a fifth fire pump, and a longitudinal bulkhead during the detail design phase. The area of design margins is controversial and requires additional study.

In spite of the problems associated with the design budgets, the PF design was more effectively controlled than any previous NAVSEC design.(37) The design budget is not, and was never meant to be, a design procedure. It is an accounting system for engineering properties and costs and was a useful method for maintaining the visibility of crucial design parameters.

Prior to the configuration freeze in the later stages of preliminary design, the change review process should be relatively informal. Too much formality was used in the PF preliminary design, and this made the control process too unwieldy.(37) After the freeze of the preliminary



design, a configuration control baseline (CCBL) was established. The CCBL consisted of budgets (weight, manning, etc.), master equipment lists (MEL), and arrangement drawings.

Formal change control procedures were adopted to maintain control over the ship design. These procedures were initiated within NAVSEC with the establishment of a configuration control baseline. The baseline grew in scope as decisions were made regarding subsystem tradeoffs until completion of the functional baseline. The functional baseline was used as the initiation point for the contract design.

With the approval of the Lead Ship Allocated Baseline (LSABL), the configuration control functions of NAVSEC transferred to the PF Ship Acquisition Project Manager (SHAPM) in the Naval Ship Systems Command. The role of design agent shifted from the Navy (NAVSEC) to a private contractor for the detail design. The SHAPM enforces configuration control through contractual agreements with the design agent.

### 2.3 Summary of Chapter 2 Conclusions

1. The Navy went through a systematic process of evaluating future fleet requirements and projected acquisition resources to arrive at a definite need for a small escort ship.





2. In the conceptual design phase, the Navy examined a large number of ship alternatives and proposed the best of these alternatives to the Chief of Naval Operations for selection of a ship weapons system. Because OPNAV did not select the complete combat system until after conceptual design, conceptual baseline cost estimate was only of Class F "ballpark" quality.

3. Admiral Zumwalt selected cost and weight constraints of approximately 10% below the conceptual baseline estimates for a ship with the selected weapons system. As will be shown in Chapter 3, the weight constraint was unreasonably low. The values of these constraints were based more on the feeling of what was possible than on sound engineering analysis.

4. The manning constraint is another example of an OPNAV decision made on an impulse, without knowing all of the effects of this decision. The reduction in manning did result in the ability to maintain a relatively small weight and volume fraction devoted to personnel without a reduction in the Navy's habitability standards. This reduction in manning, however, required additional automated equipment and the initiation of a new maintenance philosophy. The planning for "maintenance by replacement" started in late 1974, and the true cost of this reduction in shipboard maintenance is still unknown. Life cycle cost was sacrificed for a lower acquisition cost and increased habitability, but the full cost of that decision may not be known for years.



5. The setting of design constraints influences the entire ship design process and therefore should be done in a rational manner, based on a technical assessment of the design problem. The respective roles of the operator and the ship design manager should be reviewed and clarified. The operator should make decisions associated with the performance requirements of a new ship and should make the performance/cost tradeoff decisions. But the technical decisions and technical aspects of the ship design must be under the cognizance of technically trained personnel. The technical management must ensure that the cost/performance tradeoff decisions are made on a sound technical basis.

6. Although the Patrol Frigate is advertised as a design-to-cost ship, final ship cost was not directly controlled as a design parameter. System and subsystem cost tradeoffs were made on the basis of marginal cost factors or cost deltas.

7. The NAVSEC design team used a complex budget system to control the ship design. The designers and engineers had not previously worked with a design budget, and the effort was only partially successful.

8. The most significant element in the control of the PF weight and cost was the existence of a strong Change Control Board. This board emphasized low cost and low weight in all phases of the ship design and was able to



control the growth of the design. The most successful tools for design control were the arrangement drawings and the space budget.

9. The design process has undergone an evolutionary change away from the very distinct phases of feasibility study, conceptual design, preliminary design, and contract design. Many feasibility studies are done during concept design, and yet some of the concept design effort must be done to a level of detail previously not accomplished until preliminary design. Much of the design detail previously left for contract design must now be done in preliminary design in order to be able to make the necessary cost and weight tradeoff decisions.

In spite of the problems noted above, the displacement and cost of the Patrol Frigate were controlled throughout the preliminary and contract design phases. Although the Patrol Frigate was not designed within the CNO constraints, the design team was able to control the growth of the Patrol Frigate. That was a significant victory for design-to-cost.



## CHAPTER III

### ANALYSIS OF THE PATROL FRIGATE DESIGN

#### 3.1 Introduction

The purpose of this chapter is to examine the Patrol Frigate from the viewpoint of naval ship design. The effort to keep weight below the given goal is examined, and the decisions to keep the weight and cost of the PF low are presented. The Patrol Frigate is compared with similar U.S. Naval ships to determine how the PF is different from other recent designs. The austerity decisions are quantified to determine the effect of these decisions on the PF design. Conclusions are drawn as to the effectiveness of design-to-cost and the role of the designer and the customer, the Chief of Naval Operations.

#### 3.2 Weight History of the PF

Figure 3.1 shows the cyclical nature of the Patrol Frigate estimated displacement. The PF design through the end of contract design (LSABL) was a constant battle to reach the displacement goal set by the Chief of Naval Operations. (NOTE: The terminology used in the Patrol Frigate design phase is compared with that of other designs in Figure 2.1.) With the award of the lead ship design contract, the Defense System Acquisition Review Council (DSARC) threshold displacement of 3600 tons became the controlling displacement constraint. Exceeding a DSARC





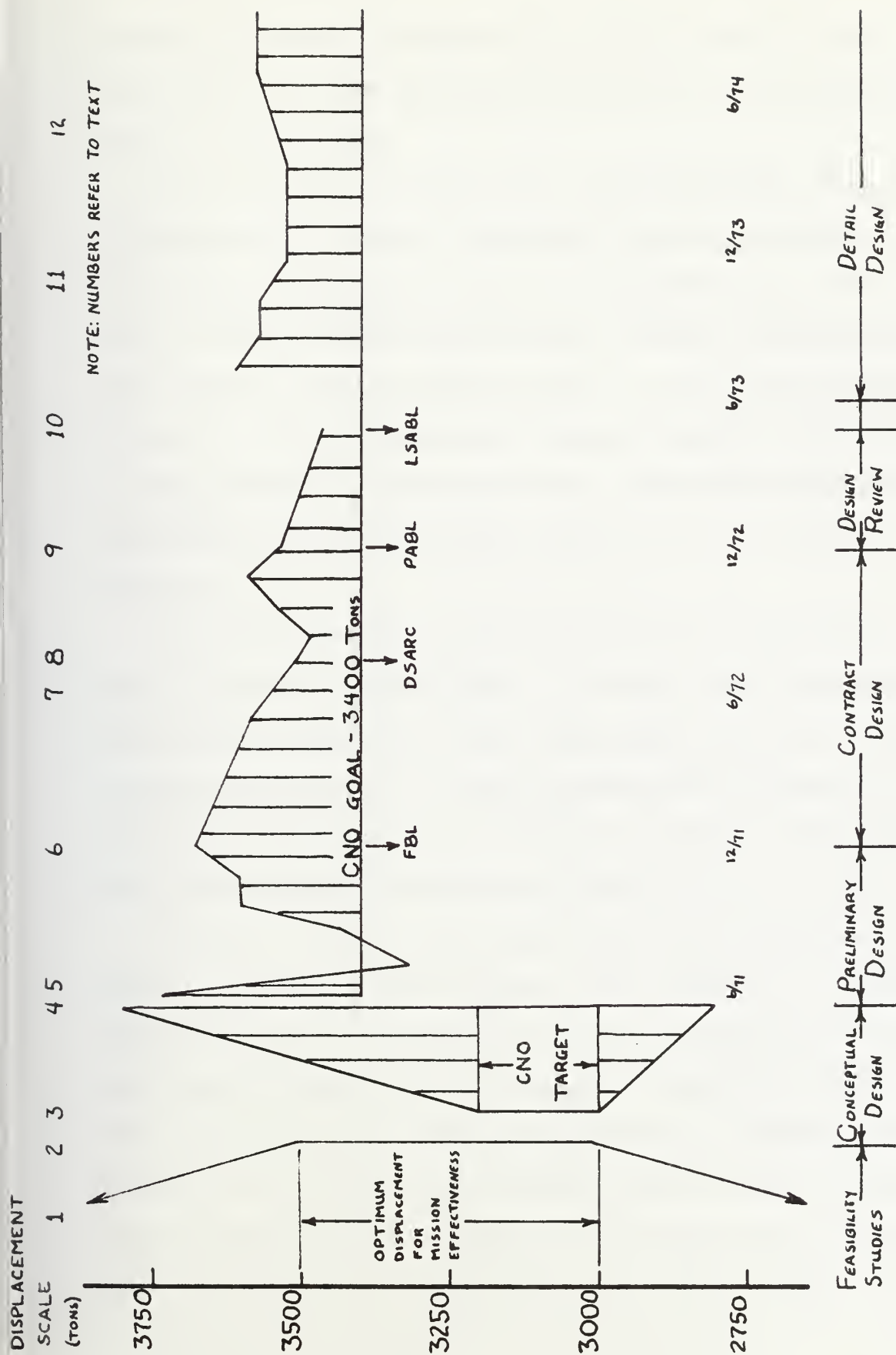


Figure 3.1. History of the Patrol Frigate Estimated Displacement



threshold requires resubmission of the program to the Secretary of Defense through the DSARC for permission to continue the program.

As described in Chapter Two, the operations analysis and feasibility studies recommended an optimum escort in the 3000-3500 ton range (Point 2 in Figure 3.1). The Chief of Naval Operations selected a target displacement of 3200 tons for the conceptual design of the Patrol Escort (Point 3). The resulting ship designs ranged from 2800 tons to 3800 tons full load displacement, depending upon the combination of weapon systems selected for the ship. (Point 4)

The CNO selected a ship with both anti-submarine and anti-air warfare capabilities. A single shaft propulsion plant was selected along with the weapons systems. The selected combination of weapon systems was estimated to result in a ship design of 435 feet in length and a full load displacement of 3675 tons (Point 5).

Several important decisions were made during conceptual design to keep the displacement low. (Table 3.1) Departure from past practice of buying only U.S. products for U.S. Navy ships allowed the selection of a lightweight gun and fire control system. Design and builders' margins were reduced by 2%. The future change characteristics margin was eliminated, and the service life margin was reduced to less than half that of previous naval ship designs. A



TABLE 3.1

AUSTERITY MEASURES FROM CONCEPTUAL DESIGN PHASE

1. Deletion of Future Change Characteristics Margin
2. Reduction in Service Life Margin
3. Decision to allow purchase of foreign designed weapon systems resulting in the selection of:
  - a. the Oto Melara gun
  - b. the Dutch design fire control system
4. Cross utilization of personnel, decreasing manning from 253 to 213 men
5. Reduction in design and builder's margins



significant effort was made to reduce shipboard manning through cross-utilization of personnel. The impact of these decisions is summarized in Table A-2. The implication of these decisions is discussed later in this chapter.

These decisions were factored into the 3675 ton weight estimate, but the CNO was not satisfied with the size of the ship. He directed that 3400 tons be the "upper limit of full load displacement".(28)

With the CNO constraint of 3400 tons, NAVSEC shortened the PF to 400 feet and estimated a displacement of 3310 tons in August 1971. By October 1971 the ship had grown to 3400 tons, and it became evident that the desired ship characteristics could not be built into a 400 foot ship. Ship length was increased to 420 feet, and displacement rose above 3600 tons. At the completion of the functional baseline design (December '71) estimated full load displacement was 3672 tons, and estimated VCG was .88 feet higher than that required to meet stability criteria.(44) (Point 6 on Figure 3.1)

Immediately following completion of the functional baseline (FBL), the design documents were reviewed by the shipbuilder (Bath Iron Works), the alternate shipbuilder (Todd), NAVSEC, NAVSHIPS, and others. It was determined that the stability and weight problems could not be solved within the present configuration. Ship length was reduced





to 400 feet. The ship rearrangement resulted in "an unidentified reduction of 100 tons and 2000 square feet of deck area".(35) As a result of the shortened hull and the implementation of some of the design review comments, the PF started contract design at 3590 tons.

In May, 1972, the Chief of Naval Operations changed the weapon systems requirements for the PF. The AN/SQS-23 (Pair) sonar was replaced by a lighter weight AN/SQS-505 sonar, and a requirement to carry a second LAMPS helicopter was added.

The ship was lengthened by eight feet in order to resolve below decks arrangements problems, but the full load displacement was lowered to 3507 tons. It was this configuration which was presented to the Defense Systems Acquisition Review Council (DSARC) in August, 1972. (Point 8)

Emphasis on weight control brought a lowering of the weight to 3490 tons before the increased design detail resulted in revision of estimated weight upward. By October, 1972, estimated weight had risen to 3580 tons, and a weight and stability improvement program was initiated. This program took a detailed look at all aspects of the Patrol Frigate design. The largest savings resulted from the deletion of the emergency diesel generator, deletion of main engine silencers and acoustic treatment, and replacement of the auxiliary steam system with a waste heat recovery system for auxiliary heating requirements. The



O-2 level was removed primarily to improve ship stability. Very little weight savings resulted from this rearrangement of spaces as no equipment or functions on the O-2 level were deleted. Many small measures were used to reduce weight including the removal of extra furniture from the Executive Officer's stateroom at a savings of 0.25 tons. It is estimated that this weight reduction program decreased displacement by over 100 tons, but growth in other areas resulted in a preliminary allocated baseline (PABL) weight estimate of 3540 tons full load displacement.(35,44)

Tables 3-2 through 3-6 list most of the austerity items initiated on the Patrol Frigate during the FBL and PABL phases of ship design. These lists were developed from the records of the NAVSEC Configuration Control Board, a rough draft of the Technical History of NAVSEC PF Design Project, and personal contact with personnel involved in the PF design. The impact of these decisions is discussed in greater detail later in this chapter.

A NAVSEC Adjudication Board (NAB) supervised a new weight reduction program and reviewed comments on the PABL design in early 1973. The efforts of the board resulted in a further reduction to the Lead Ship Allocated Baseline displacement of 3480 tons. (in April 1973, Point 10) This concluded the NAVSEC design effort.



TABLE 3.2

ENGINEERING AUSTERITY ITEMS

6. Central Workshop - all of the workshops have been combined into one space
7. Single ship's boat - most ships of this size carry one 26' motor whale boat (MWB) and one 26' personnel boat. The PF has one 26' MWB.
8. Removal of 2nd anchor, chain and windlass - normal practice is to carry two anchors, with windlass and chain for each. Initially the windlass and chain were removed, leaving the second anchor as a spare. Later the second anchor was deleted.
9. Decrease size of AFFF stations - AFFF (fire fighting) station size was decreased from 40 square feet to 25 square feet each
10. Air Compressor Selection - smaller size (4 cfh vice 20 cfh) was selected for low weight and cost at the risk of some development
11. Replace 600 HP aux. propulsion motor with 2 325 HP motors - savings in cost, weight and space by using existing submarine equipment
12. Remove milling machine-
13. Replacement of aux. boiler with waste heat system - waste heat system is run from diesel generator system. Primary savings in boiler weight and lower endurance fuel.
14. Remove oil and water test lab - not required after removal of waste heat system
15. Delete main engine silencers and acoustic treatment - allows modification of intake and exhaust allowing easier removal for maintenance



TABLE 3.2  
(con't)

16. Remove one degaussing coil - standard Navy practice would dictate four coils, only three are installed on PF
17. Reject decontamination- station required by TLR and Gen Specs - removed by SHAPM
18. Remove two fire pumps - re-evaluation of fire main requirements based on latest available information. One pump was reinstalled during detail design.
19. Deletion of cruise engine - decision made early in FBL because of marginal improvement in capabilities
20. Deletion of roll stabilization - space only provided in PABL; weight reservation added during detail design
21. Decrease in electrical- margins 30% growth margins applied to limited areas resulted in installation of only three ship service generators. Fourth generator added during detail design.
22. Substitute 12KW emergency generator for 250KW generator - emergency generator installed to protect against loss of both machinery spaces from the same casualty. Emergency load requirements were reduced to permit smaller generator.
23. New standard for calculating CPP shafting - results in significant reduction in shafting weight
24. Simplified UNREP system - missile resupply by VERTREP only
25. Inclusion of helo fuel as part of endurance fuel and sliding endurance calculation - departure from DDS requirements





TABLE 3.2  
(con't)

- |  |  |
|--|--|
| 26. No dial telephone system                                     | - normally installed on DE size ships                        |
| 27. No provision for pneumatic tubes for interior communications |  |
| 28. Less severe noise requirements than recent ship designs      | - will result in lower cost but not necessarily lower weight |
| 29. No STOPS treatment   |  |
| 30. Removal of roll tank   |  |



TABLE 3.3

PAYLOAD AUSTERITY ITEMS

- |   |   |
|---|---|
| 31. Weapons system change                 | - replacement of AN/SQS-23 (PAIR) sonar with AN/SQS-505 sonar, addition of second helicopter                              |
| 32. Remove TACTLASS                       | - sonar system did not meet timetable for production with PF. Space but <u>no</u> weight reservation for future addition. |
| 33. Remove signalman's shelter            | - equipment normally housed on O-4 level moved inside deck-house  |
| 34. No secondary conn or lookout stations |   |
| 35. Deletion of RPS custodian's office    | - functions moved inside communications center  |
| 36. Deletion of monorail hoist in hanger  | - 5-ton hoist and monorail system replaced by portable 1-ton hoists   |



TABLE 3.4

HULL STRUCTURE AUSTERITY ITEMS

- |  |   |
|--|---|
| 37. Remove ECM equipment room on O-2 level   | - equipment installed on O-1 level - improved stability   |
| 38. Replace circular chain lockers with built-in lockers                                       |   |
| 39. Remove deckhouse front, side bulwarks and fashion plates, reduction in size of bridge wing | - installed on most DE ships to protect personnel against green water (waves). Believed unnecessary with PF hull design.                              |
| 40. Rearrangement of tanks to save weight  | - tanks arranged to make better use of structural bulkheads   |
| 41. Remove unnecessary bulkhead between Mk92 & CIC cooling rooms                               |   |
| 42. Remove longitudinal bulkhead aft   | - originally installed to reduce vibration from screw, removed as unnecessary in PABL, reinstalled during detail design                               |
| 43. Reduced Structural margins   | - 1.0 tons per square inch primary stress margin for future displacement growth reduced to .75 tsi since little future displacement growth is planned |
| 44. Extensive use of GRP   | - glass reinforced plastic used in many non-structural applications   |
| 45. Removal of unnecessary watertight hatches  |   |
| 46. Reduce helicopter platform structural design criteria                                      |   |
| 47. No external inclined ladders   |   |



TABLE 3.5

PERSONNEL AUSTERITY ITEMS

- |   |   |
|---|---|
| 48. Decreased manning   | - dictated by CNO   |
| 49. Reject increase in medical spaces                                 | - reduction in space of proposed medical treatment room without reducing capability               |
| 50. Combined galley   | - substitution of officer's pantry for galley - similar to submarine arrangement                  |
| 51. Removal of spare furniture  | - executive officer's stateroom is designed for two men, furniture for second officer was removed |
| 52. Medical treatment room doubles as forward battle dressing station | - eliminates need for Battle Dressing Station   |
| 53. No provision room   | - combined with other supply spaces   |
| 54. Remote engine operation   | - unmanned engine room allows reduced manning   |
| 55. Maintenance by replacement  | - transfer maintenance functions ashore to reduce shipboard manning                               |





TABLE 3.6

POLICY AND ACQUISITION DECISIONS RELATED TO DESIGN-TO-COST

- |  |  |
|--|--|
| 56. Lead ship/Follow ship concept                      | - extended the time between first and second ships to allow for verification of design before followship contract  |
| 57. Multi-year/Multi-ship contracting for follow ships | - larger ship contracts to take advantage of economics of scale  |
| 58. Risk management                                    | <ul style="list-style-type: none"> <li>- selection of low risk equipment</li> <li>- systems and equipment validation through extensive test and evaluation program</li> </ul>  |
| 59. Emphasis on standardization                        | - use of standardized equipment within the class and within the Navy including use of options on some subsystem procurements   |
| 60. Definition of cost ceiling                         | <ul style="list-style-type: none"> <li>- excluding shipbuilder acquisition costs</li> <li>- excluding outfitting and post delivery requirements</li> <li>- constant dollars</li> <li>- based on specified ship quantities</li> </ul> |



The detail design of the Patrol Frigate is being done by the Naval Architectural firm of Gibbs and Cox. The first detail design weight report in July, 1973, estimated the Patrol Frigate as greater than 3600 tons full load displacement. The Navy and Gibbs and Cox reviewed this weight report line item by line item and reached an agreement on an estimated weight of 3560 tons. The Navy directed Gibbs and Cox to reduce the Design and Builders Margin by another 30 tons to reach full load displacement of 3530 tons in March 1974.(61) The subject of margins is discussed more fully later in this section.

During the detail design three major decisions were made which have increased the PF displacement to 3585 tons (Point 11). A fourth diesel generator was added to the PF electric plant at a total cost of 50 tons displacement and the after longitudinal bulkhead removed during PABL was designed back into the PF. The fin stabilizers were changed from a space reservation only to a space and weight reservation. The 75 ton service life margin was reduced to 50 tons to compensate for the weight of the fin stabilizers. These decisions are discussed in more detail in Section 3.2. The detail design has proceeded without increasing above 3585 tons from September, 1974, through March, 1975.

Figure 3.2 shows a comparison between the light ship weight of three ships at various stages in the design effort (normalized to preliminary design displacement).



Normalized  
Light Ship  
Displacement

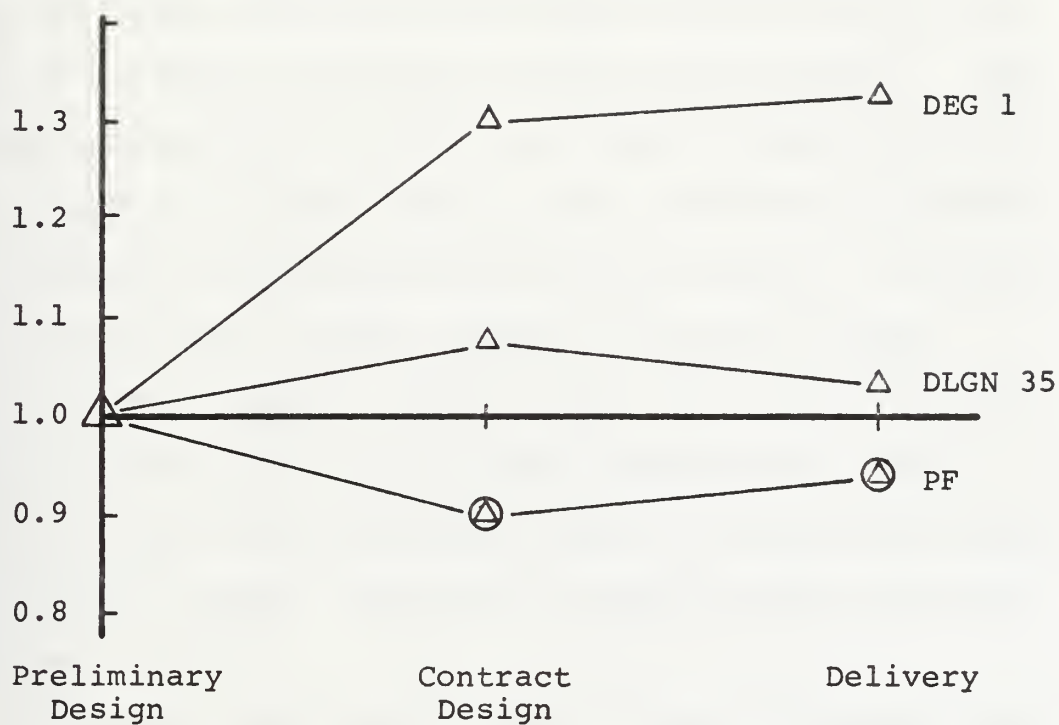


Figure 3.2. Light Ship Displacement Growth During Design

$$\text{Normalized Light Ship Displacement} = \left( \frac{\text{Displacement}}{\text{Preliminary Design Displacement}} \right)$$



Care must be taken when comparing the weights of ships because the design phases may not be compatible. Since the conceptual design phase of the PF approximates the level of detail previously accomplished in the preliminary design phase, the PF weight is normalized to the conceptual design weight, prior to the imposition of constraints. While the DEG-1 and DLGN-35 increased in light ship weight during the design, the Patrol Frigate has decreased. Most of the increases in the DEG-1 and DLGN-38 weight, however, came during the contract design phase, while the increase in PF weight is occurring during detail design. It should be noted that the PF final weight is from the latest available weight report (March, 1975) while the DEG-1 and DLGN-35 weights are from inclining experiments. The PF may grow larger if she uses the rest of the assigned design and builder's margin. The area of design growth deserves additional study.

In several areas the PF design differs from past naval ship designs. Section 3.3 compares the PF with similar U.S. ships.

### 3.3 The Patrol Frigate Compared With Similar U.S. Naval Ships

The purpose of this section is to compare the Patrol Frigate with similar U.S. naval ships to determine where this ship differs from other designs. These differences are then compared with the austerity measures listed in Section 3.2 to evaluate the effect of design-to-cost.





The PF is compared with six other post-World War Two destroyer designs, the DE-1037, DE-1040, DE-1052, DEG-1, DDG-2, and DD-931. The "as-built" condition is used for comparison because of the availability of weight and volume information and to provide a consistent data base. The characteristics of these ships are shown in Table 3.7. Figures 3.3 through 3.11 present this comparison. The PF is highlighted by a double symbol on these graphs.

Figure 3.3 shows the trend of increasing displacement of destroyer escort size ships over the past twenty years. This increase in size has been caused primarily by a desire for increased ship performance (greater payload carrying capability, speed, habitability, etc.). The Patrol Frigate reversed this trend of ever-increasing ship size. A similar graph of destroyer displacement versus time would show that the design-to-cost DG-AEGIS also reverses the trend of increasing ship displacements.

Figure 3.4 shows the division of full load displacement into categories describing the use of that weight as structure, engineering, payload, and personnel. Table 3.8 shows the division of space and weight into these categories and indicates the relationship with the Ship's Work Break-down Structure for categorizing weights and the proposed NAVSEC space classification guide for space allocation. The PF is not significantly different from other similar ships



TABLE 3.7

SHIP DATA (6,45)

Ship Class	DE-1037	DE-1040	DE-1052	DEG-1	PF-109	DDG-2	DD-931
Year First Completed	1963	1964	1969	1966	1977	1960	1955
Full Load Displacement(note 1)	2650	3400	4100	3425	3540	4526	4034
Type of Power Plant	600 psi steam	pressure fired steam	1200 psi steam	pressure fired steam	COGAG	1200 psi steam	1200 psi steam
SHP	20,000	35,000	35,000	35,000	40,000	70,000	70,000
Total Power	22815	37681	39021	37681	44021	72949	72949
No. Shafts	1	1	1	1	1	2	2
ASW Systems	ASROC 6TT	ASROC 6TT	ASROC 4TT	ASROC 6TT	6TT	ASROC 6TT	Hedgehogs 4TT
Missile Systems	--	--	Note 2	Tartar	Standard Harpoon	Tartar	--
Guns	3 3"/50	2 5"/38	1 5"/54	1 5"/38	1 76 MM	1 5"/54	3 5"/54 4 3"/50
Helicopter	--	Note 3	Notes 2,3	Note 3	2 LAMPS	--	--



TABLE 3.7

NOTES

Note 1: All information is from Jane's Fighting Ships and NAVSHIPS Publication "Building Escort Ships and Patrol Frigates for the United States Navy". Ships are listed as "as-built" condition except for PF which is as designed in the PABL.

Note 2: None "as-built", Sea Sparrow missile system and 1 LAMPS helo were added in modernization, but not included in analysis.

Note 3: Originally designed with unmanned DASH helicopter.



TABLE 3.8

DIVISION OF SPACE AND WEIGHT INTO CATEGORIES FOR ANALYSIS

<u>Area</u>	<u>Weight</u>	<u>Volume</u>
Hull (Structural)	Group 1	
Engineering	Groups 2,3.5 Reserve Feed Fuel Oil (endurance) Lube Oil	Groups 3.2, 3.3, 3.4 Engineering Control from 3.1 Fuel Oil from 3.5
Payload	Groups 4 & 7 Ammunition Aircraft JP-5 Aero/Ord Stores	Group 1 Ship Control from 3.1 Payload from 3.5
Personnel	Group 6 Officers, Crew & Effects Stores Potable Water	Group 2
Passageway/Access		Group 3.7

- NOTES: 1) All weights except PF are based on as-built condition.
- 2) PF based on Contract Design-[Preliminary Allocated Baseline - PABL].
- 3) Weight groups are from ship weight breakdown structure.
- 4) Space groups are from the proposed ship space classification guide.





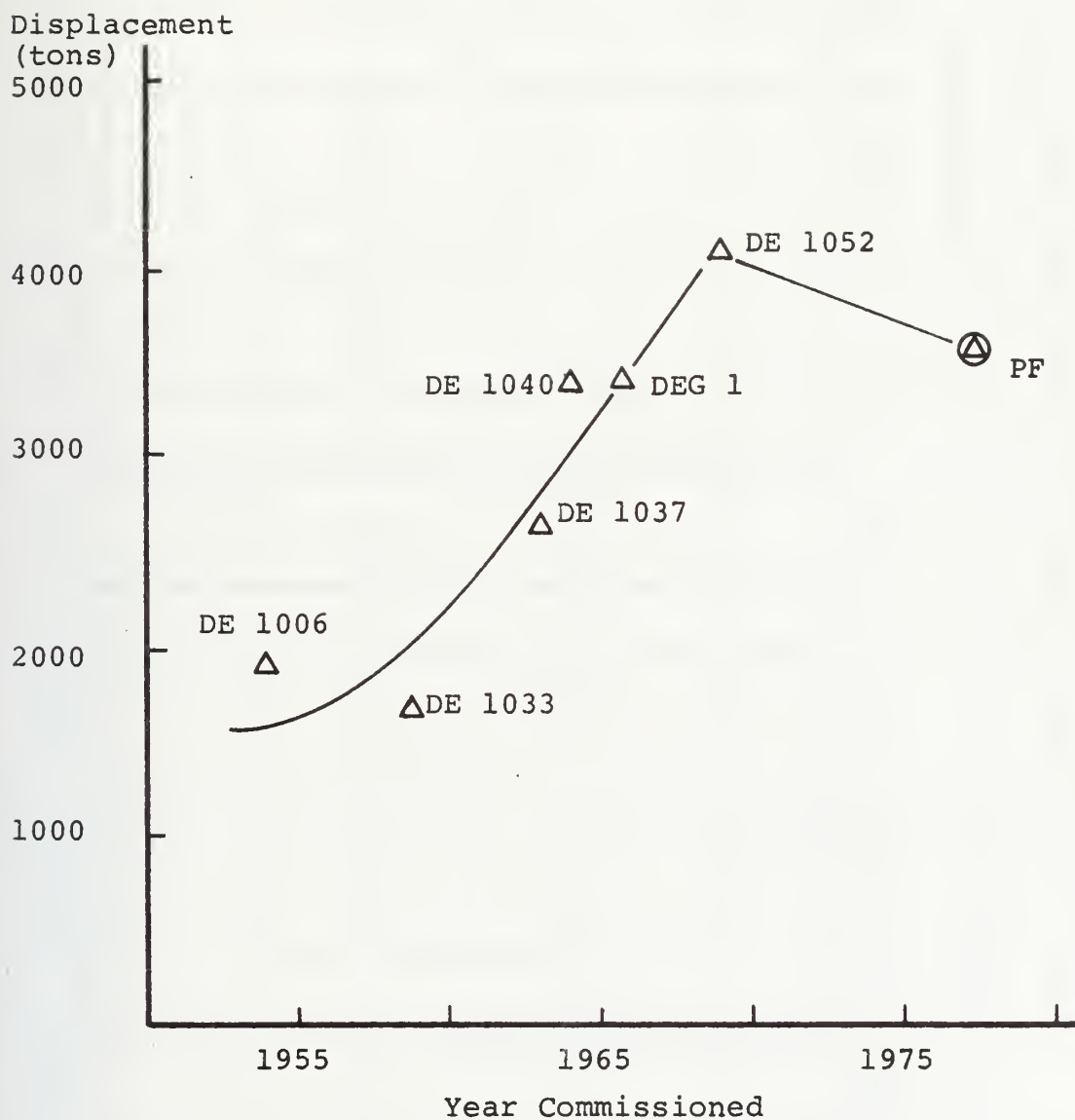


Figure 3.3. Displacement vs. Year Commissioned for Post World War Two Destroyer Escorts



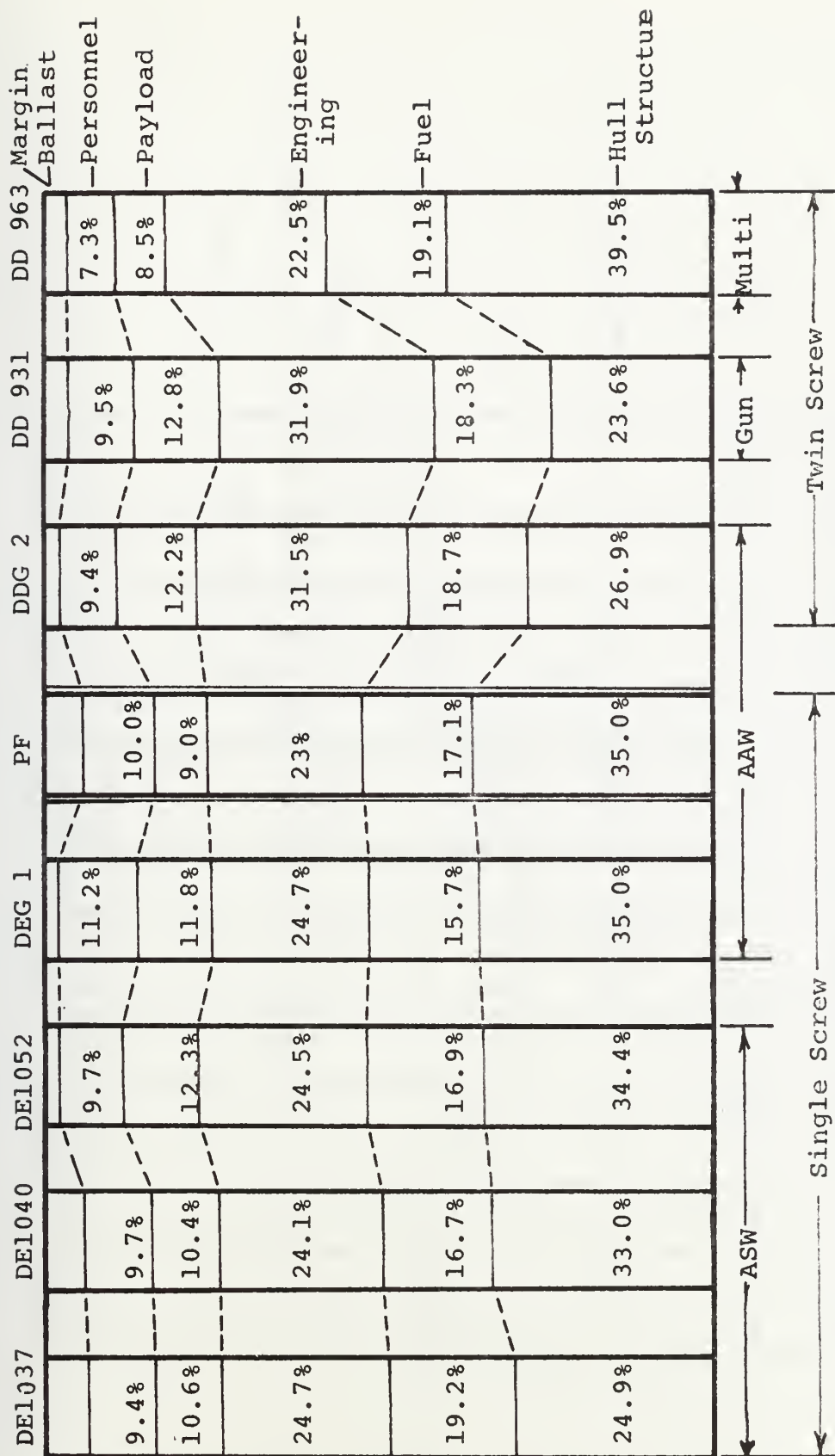
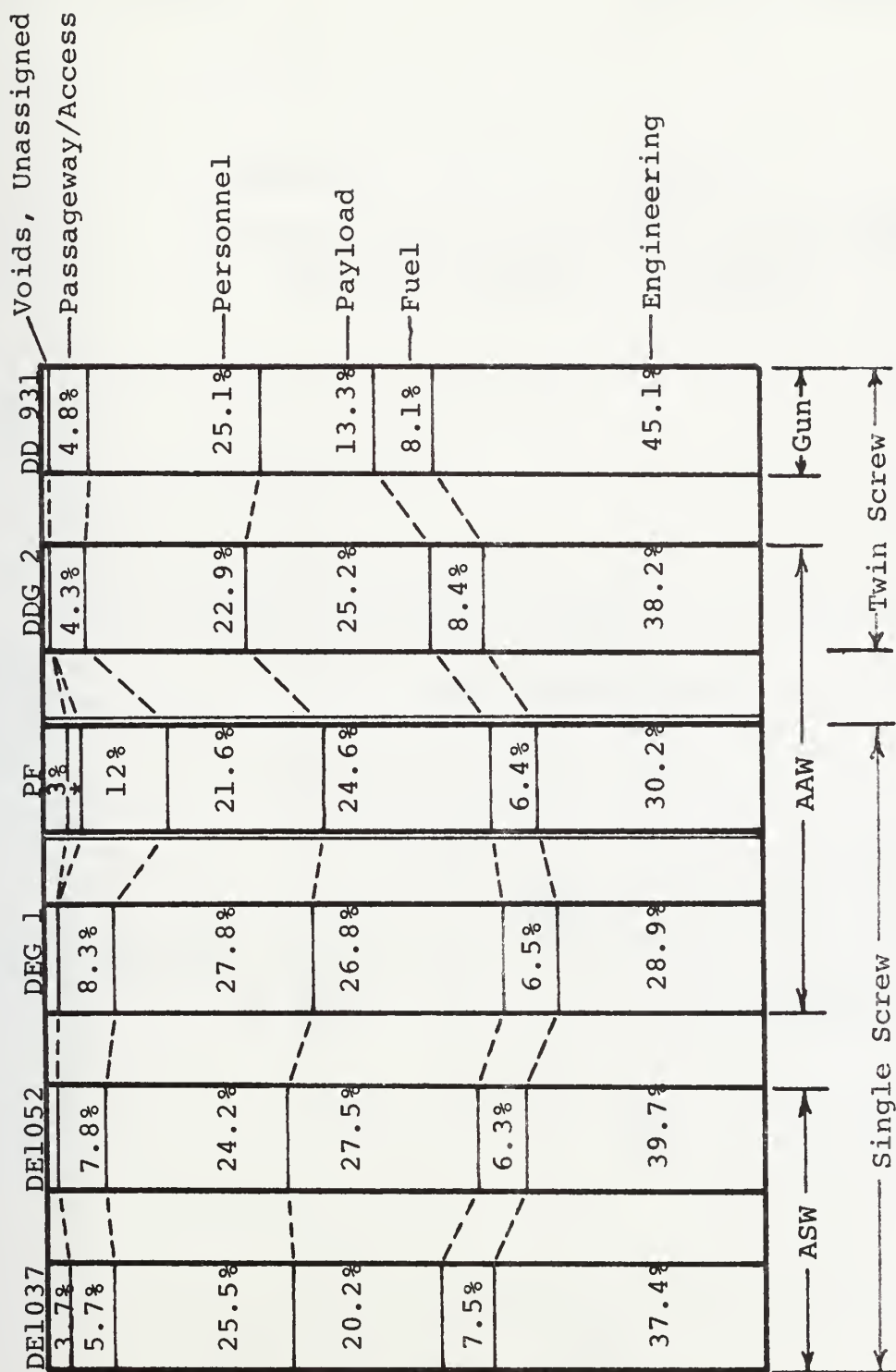


Figure 3.4. Allocation of Weight by Function in Destroyers and Frigates (DE)





\* PF - 2% Clean Ballast

Figure 3.5. Use of Internal Ship Volume in Destroyers and Frigates (DE)



Ship Density ( $\frac{\text{pounds}}{\text{cu.ft.}}$ )

$$\text{Ship Density} = \frac{\text{Displacement}}{\text{Enclosed Vol.}}$$

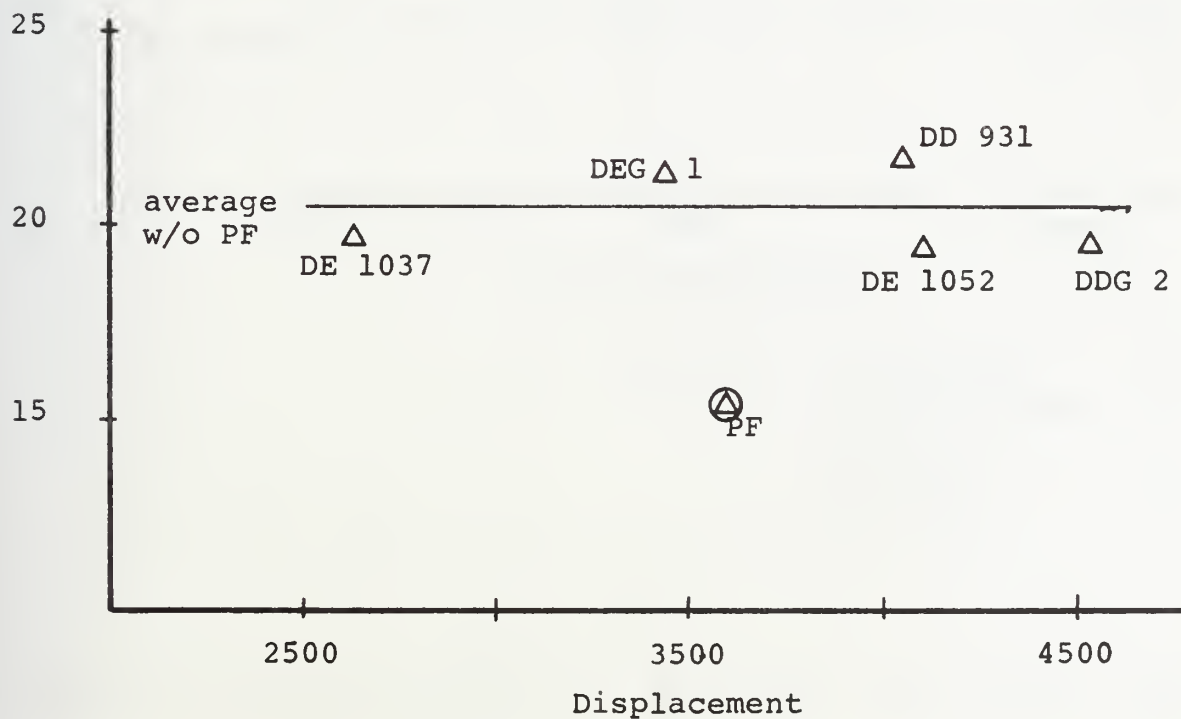
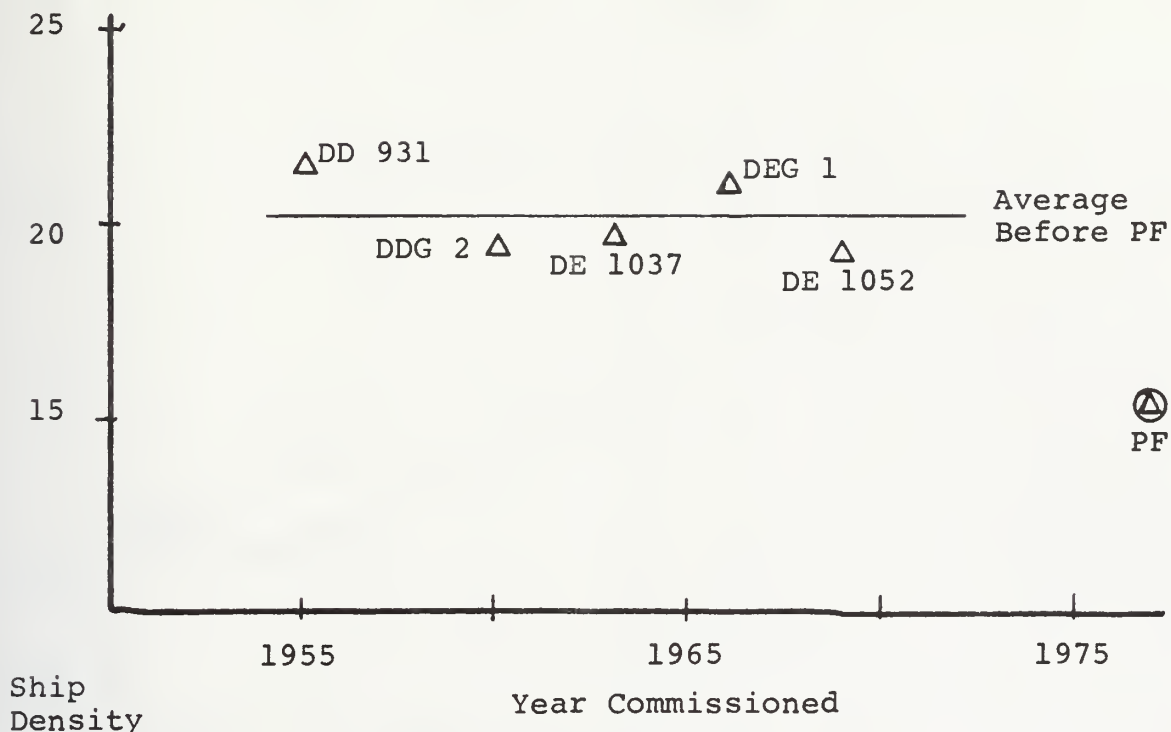


Figure 3.6. Density of Destroyers and Frigates (DE)





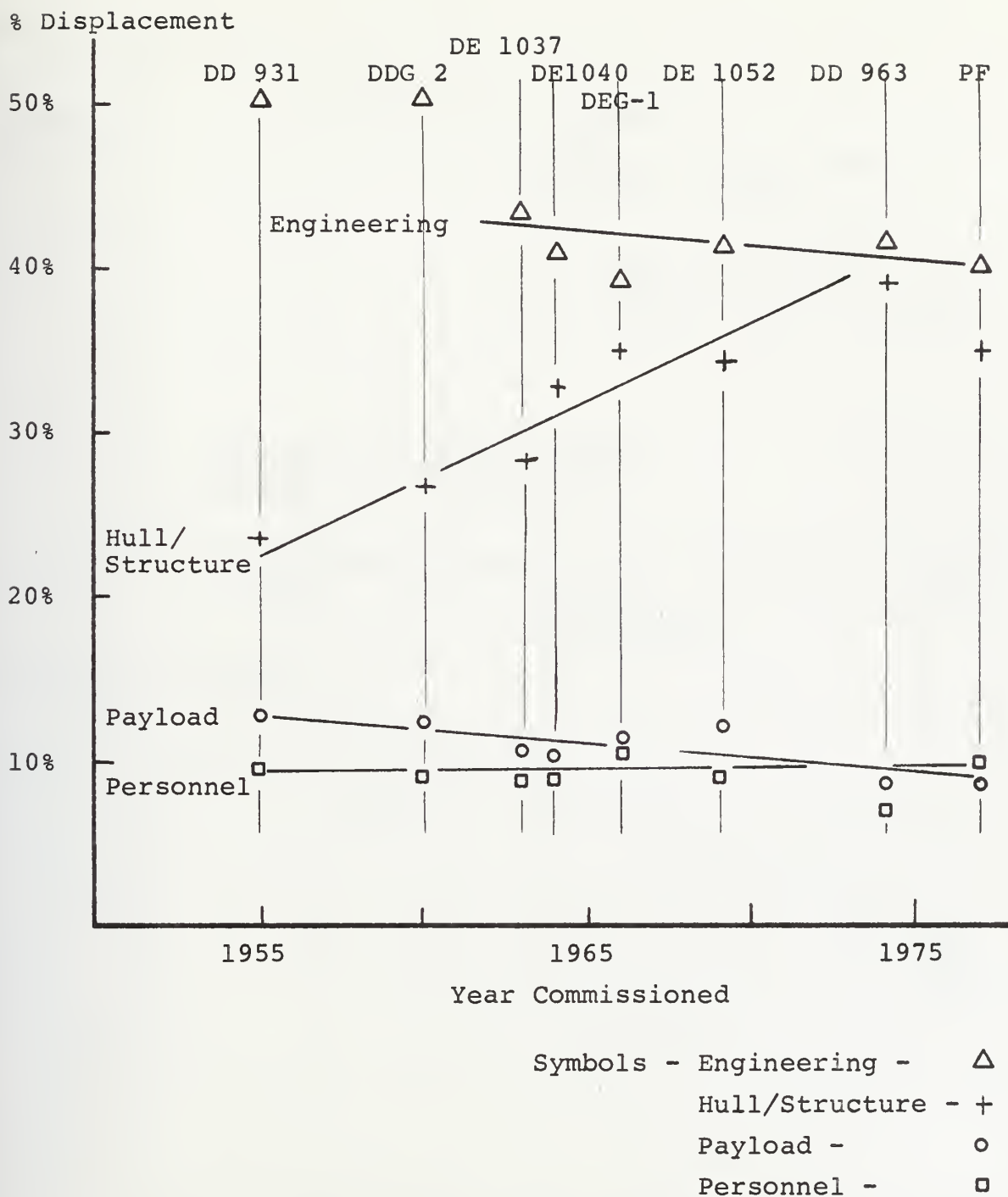


Figure 3.7. Weight Fraction for Destroyers and Frigates (DE)



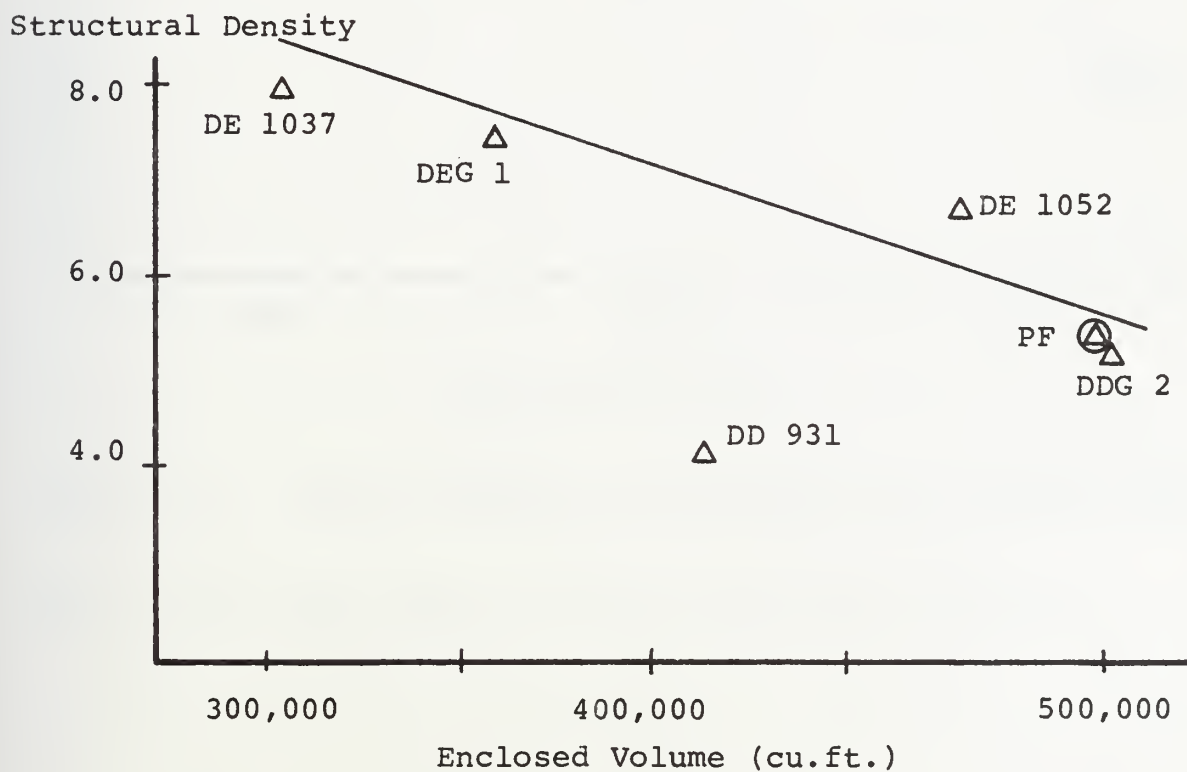
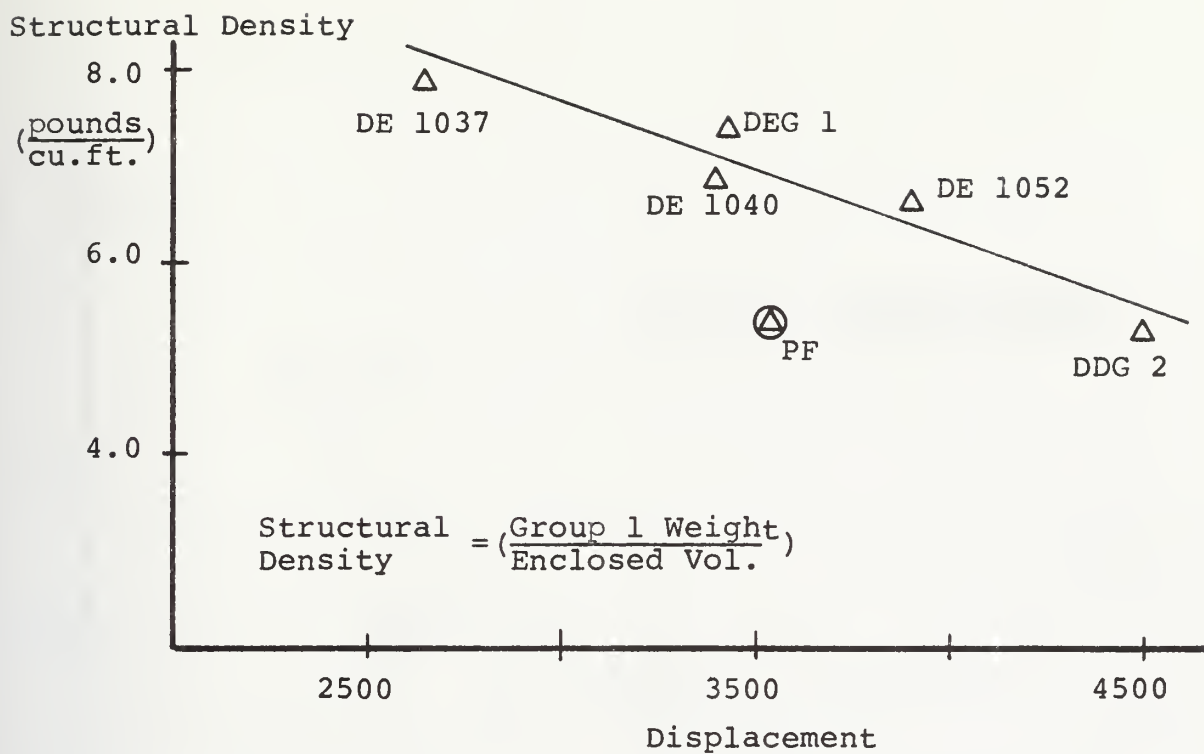


Figure 3.8. Structural Density of Destroyers and Frigates



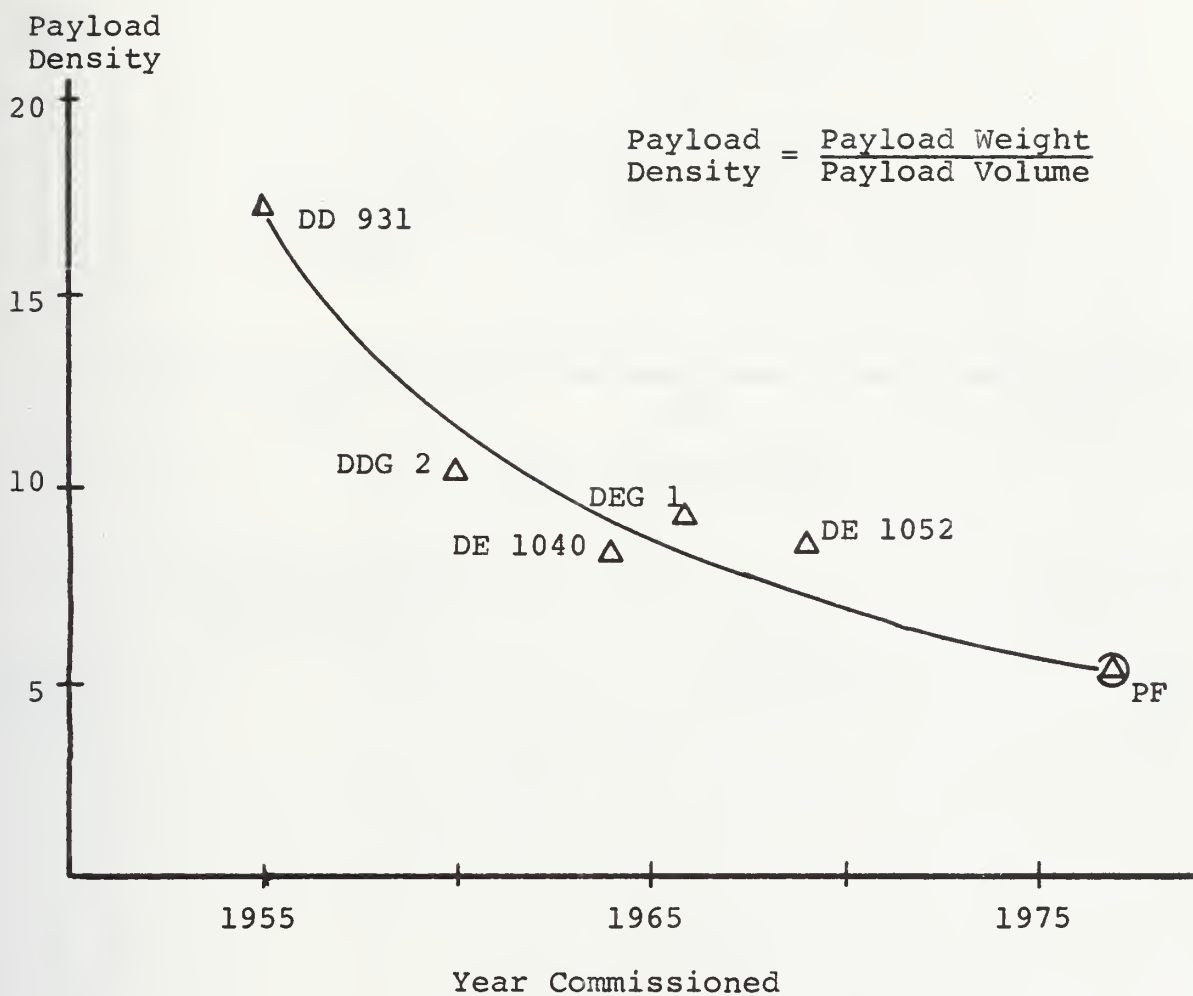


Figure 3.9. Payload Density for Destroyers and Frigates (DE)

Note: This graph depicts as-built condition of ships.



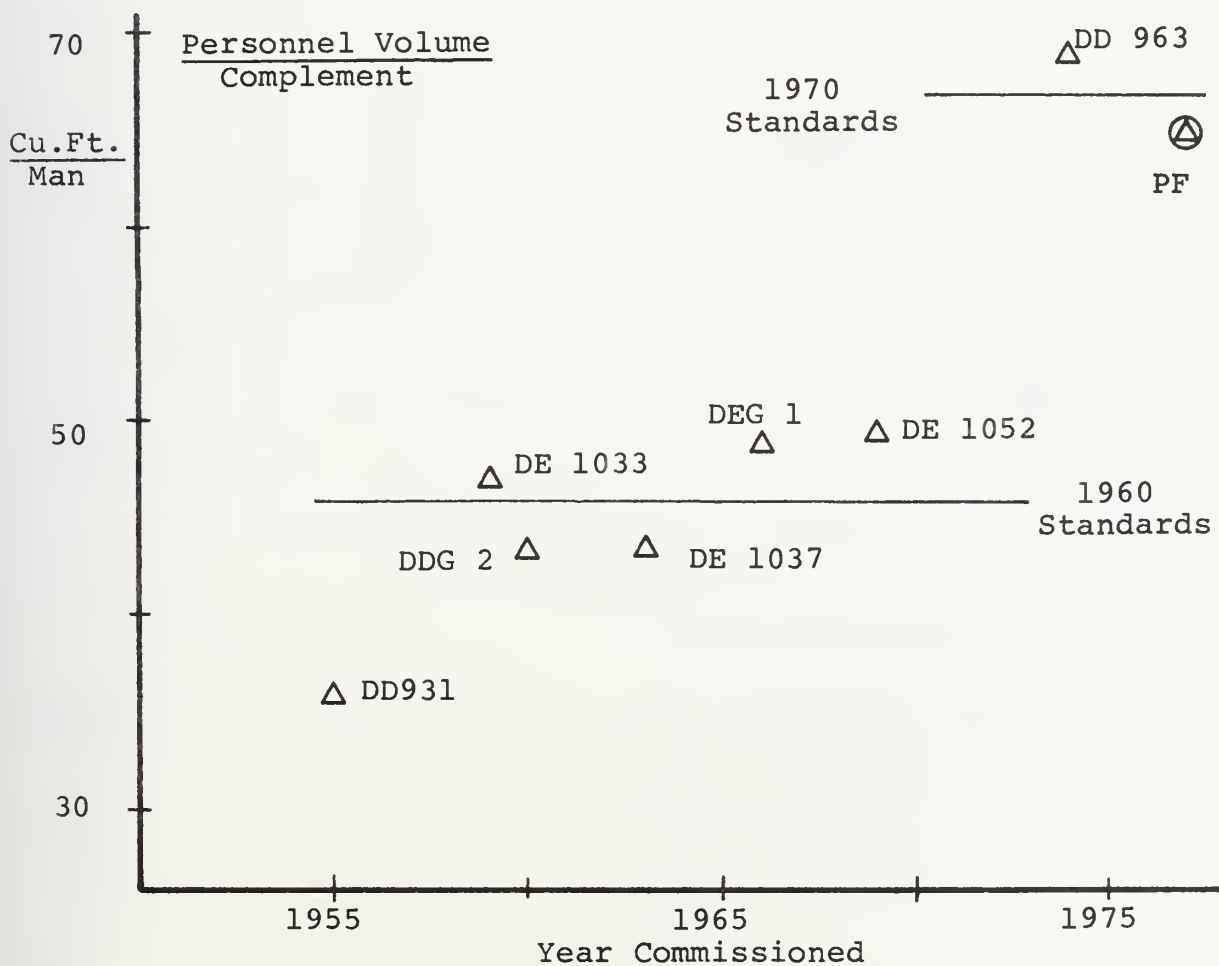
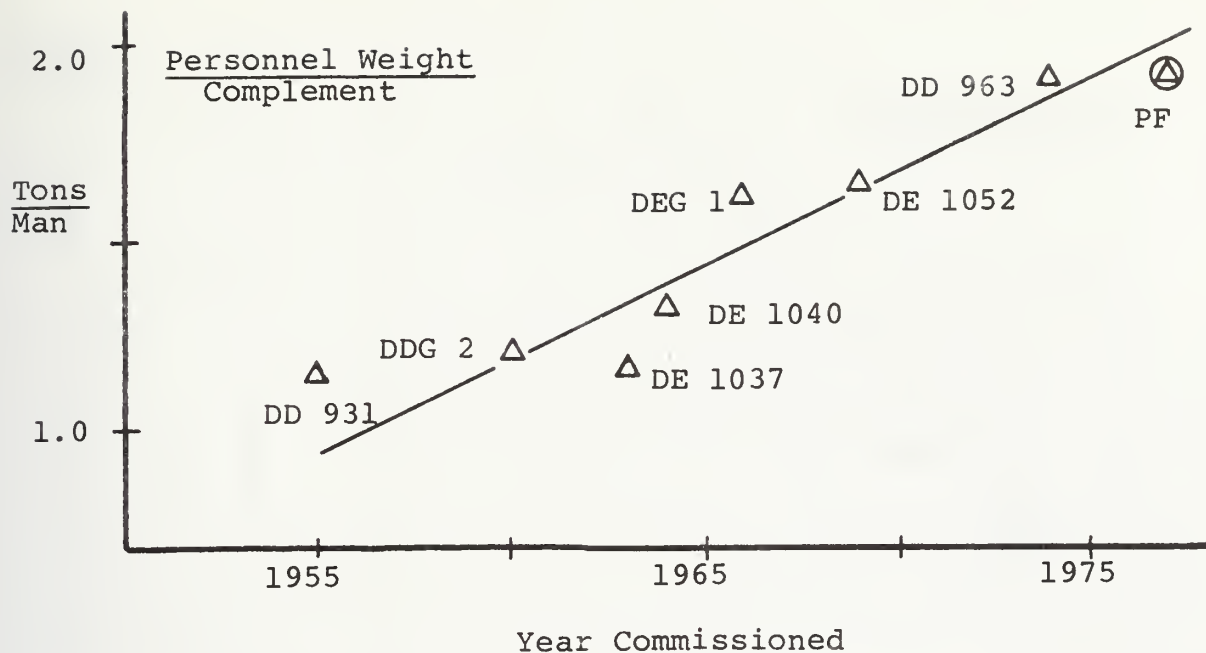


Figure 3.10. Personnel Densities for Destroyers and Frigates





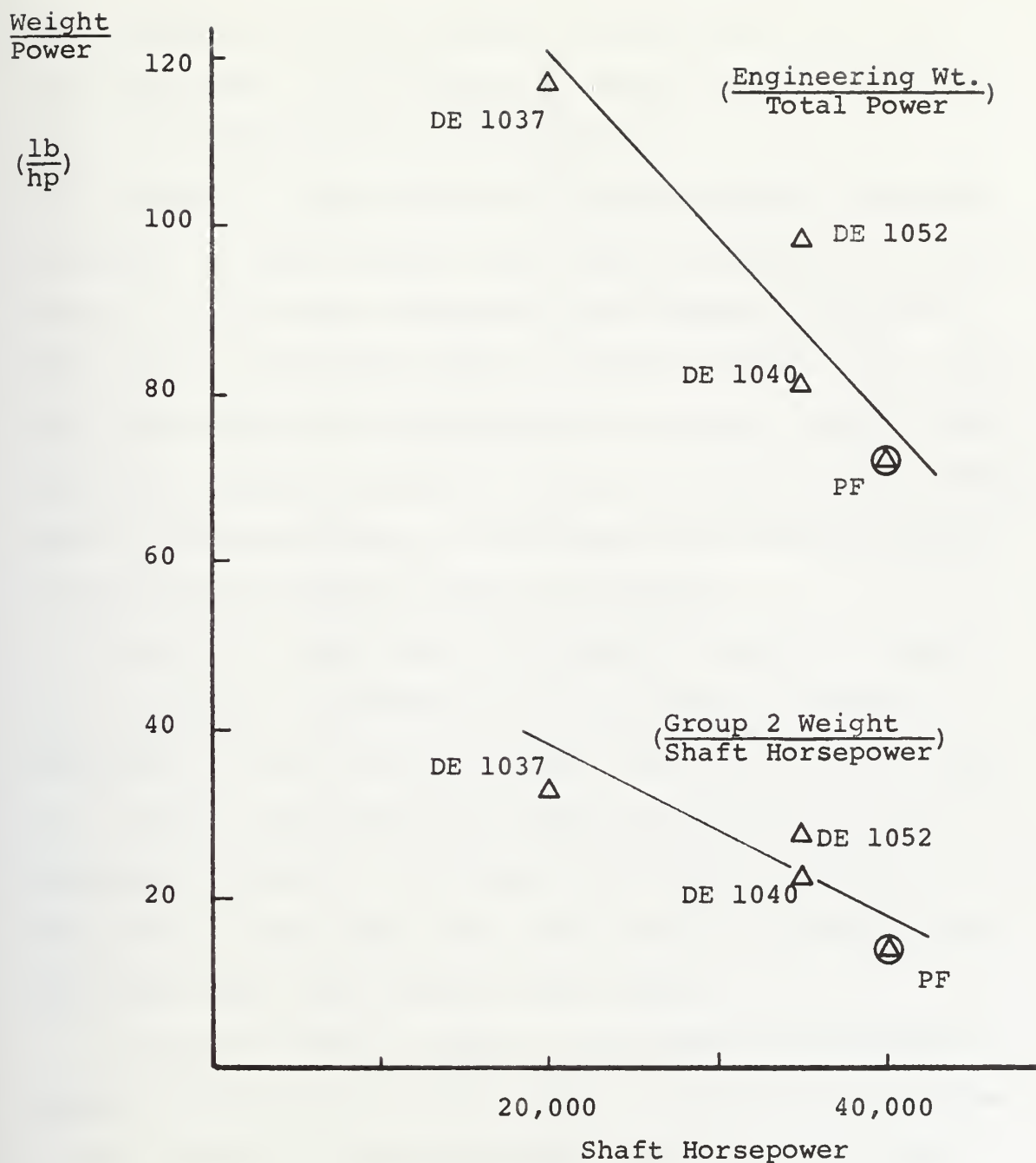


Figure 3.11. Power Plant Densities for Single Shaft Escorts

Ship Class	Power Plant Type
DE 1037	600 psi steam
DE 1040	Pressure fired
DE 1052	1200 psi steam
PF	COGAG



in the percent of weight devoted to structure, but this class does show a high percent of weight used by personnel and a low percent used in the payload.

Figure 3.5 shows the use of ship's volume by function. The Patrol Frigate devotes less space to personnel and less space to payload than comparable ship designs, the DDG-2, DEG-1 and DE-1052 class ships. The PF, however, has a very large area devoted to passageways and access. Some of this passageway can be considered personnel volume as the reduced manning and maintenance by replacement philosophy resulted in the need for better access to equipment.

Figure 3.6 shows that the internal density of small U.S. destroyers (2500-4500 tons) has remained constant, regardless of ship size or payload until the design of the PF. Internal ship density is measured as full load displacement divided by total enclosed volume in pounds per cubic foot. This graph shows that the PF is significantly less dense than other similar size ships.

Figure 3.7 shows a trend of decreasing the percent of weight devoted to engineering and payload with an increase in the percent of weight devoted to structure. To understand this graph and Figure 3.6, one must examine the specific density of the four categories which make up the ship weight.



Figure 3.8 shows a trend of decreasing structural density (group 1 weight/enclosed volume) with increasing ship displacement and increasing total enclosed volume. The PF and the all-gun DD-931 have a significantly lower structural density than that shown by the trend line; however, in the relationship between structural density and total enclosed volume, the PF structural density is consistent with previous ship designs.

Figure 3.9 shows payload density decreasing with time. The trend of this curve is caused by the shift from the gun as the primary weapon to lightweight, large volume missile systems and helicopters. The PF accentuates this trend with the shift to lightweight foreign weapon systems. (See Section 3.4.5)

Figure 3.10 shows the effect of increased emphasis on habitability on both weight and volume. The PF was able to meet the latest habitability standards without devoting an inordinate amount of space and weight to personnel through a new maintenance and operating philosophy which decreased required shipboard manning. (See Section 3.4.2)

Figure 3.11 shows a decreasing specific engineering plant density (in pounds per horsepower) with increasing shaft horsepower. A similar graph would show a decreasing density with time. A closer look at the engineering plants, however, shows that this decrease is due to advancing technology, a 600 psi steam plant, followed by a 1200 psi steam plant, followed by a gas turbine power plant.



Several general conclusions can be drawn from a comparison of the Patrol Frigate with other U.S. Navy ships.

The PF has approximately the same internal volume, but a displacement of 500 tons less than the DE-1052 class escort. (Table 3.15) This implies that the two ships are the same size, but the PF has more volume above water. This was accomplished through a shift to less dense components (weapons, propulsion, and personnel) than previous ship designs. The wider passageways and the tanks for control of environmental pollution also decrease the internal density of the PF. The low density of the PF is shown very clearly in Figure 3.3.

Allocation of weight by function is very similar to the DEG-1 class escort, with the exception of a lower payload weight. The lower payload weight of the PF is a result of the use of a lightweight gun and a smaller sonar on the PF.

Payload density (payload weight/payload volume) and specific machinery weight (engineering weight/total power) have both decreased, primarily as a result of technological advances. Space and weight per man devoted to personnel have increased with increasing standards of habitability, but the percent of the ship, both in space and weight, devoted to personnel has not changed appreciably because of the emphasis on reduced manning. There have been no





significant savings from hull structural innovations on the PF. It is unlikely that there can be any changes in ship structural weight densities without resorting to expensive lightweight materials.

### 3.4 The Effect of the Design-to-Cost Concept on the PF Design

#### 3.4.1 Introduction

In this section an attempt is made to quantify the results of design-to-cost, to answer the question, "What would the displacement of the Patrol Frigate have been without the strong emphasis on weight control executed throughout the ship's design?". The result is summarized in Table 3.9 and interpreted in Section 3.4.8.

The effect of design-to-cost is calculated by assigning a numerical value of weight, volume, or space to the austerity items listed in Tables 3.1 through 3.5, wherever possible. The analysis of the austerity items was developed from the records of the NAVSEC Configuration Control Board, a rough draft of the Technical History of the NAVSEC PF Design Project, and personal contact with personnel involved with the PF design. These resources are not consistent in the evaluation of the effect of these austerity items. Some of the effects are recorded as deck area, some as internal volume, some as weight, and some as a combination of the three effects. Secondary effects, such as electrical power and auxiliary services



TABLE 3.9

CALCULATED EFFECT OF DESIGN-TO-COST

Conceptual Design (Table A-2)	343.8
FBL/PABL Engineering (A-3)	294.5
FBL/PABL Payload (A-4)	115.4
FBL/PABL Hull (A-5)	31
FBL/PABL Personnel (A-6)	104.4
Endurance Fuel	<u>130</u>
Total Effect	+1019.1
PF PABL Displacement (12/72)	<u>3540.</u>
PF without Design-to-Cost emphasis	<u>4559.1</u>
Effect of Second Shaft	+ <u>400</u>
Twin Shaft PF without design- to-cost emphasis	<u>4959.1</u>

## Effect of Inverse Design-to-Cost

Under NAVSEC Control	- 43.5
Not under NAVSEC Control	- <u>170.9</u>
Total Effect	- 214.4
PABL Displacement	<u>3540.</u>
Possible PF displacement	<u>3326</u>



were rarely considered (at least not in the records of the Change Control Board). Tables A-2 through A-7 represent the author's best judgment as to the effect of each change, based on the available sources.

The total effect of these decisions as summarized in Table 3.9 is probably conservative because the secondary effects such as auxiliary systems requirements and electrical power are not included in many cases. In addition, there were probably other growth areas which were not proposed to the Change Control Board because the philosophy of an austere ship was emphasized by the ship design manager. Most of the weight savings, however, is concentrated in a few major decisions, and it is not likely that other growth areas would accumulate a large addition to the estimated numbers.

The tables in Appendix A are divided into seven categories--conceptual design phase, engineering, payload, hull structure, personnel, acquisition, and unquantifiable.

The unquantifiable decisions (Table A-9) are those for which the author could not substantiate a quantitative estimate of the effect on full load displacement. Most of the items on this list represent minor weight reduction, so that the cumulative effect of the omission of these sixteen austerity decisions will not significantly effect the conclusions drawn from this analysis. The acquisition policy decisions (Table A-8) include those decisions which



contribute to reduced follow ship acquisition cost, but are not easy to quantify. Most of these decisions are based on sound management practices, not necessarily a result of design-to-cost, and would be included in a large ship procurement project regardless of cost policies. Acquisition policy is discussed in greater detail by Newcomb and DiTrapani.(12,13)

The conceptual austerity design decisions (Table A-2) were discussed earlier in this chapter. The design decisions made during preliminary and contract design are divided into the same four weight categories used in Section 3.2 and 3.3. A review of these tables with the graphs in Section 3.3 shows that a majority of the weight savings was accomplished in four major areas:

1. Reduction in margins and the elimination of future characteristics change margins.
2. Reduction in shipboard manning and retention of high standards of habitability.
3. Propulsion plant selection.
4. Payload selection.

These areas are discussed in Sections 3.4.2 through 3.4.5. Section 3.4.6 discusses inverse design-to-cost. Inverse design-to-cost decisions are those decisions that will cause the ship to increase in size. These decisions generally run contrary to the austere philosophy of the PF design. Section 3.4.7 discusses the limitations of this analysis, and Section 3.4.8 draws some conclusions from this analysis.





### 3.4.2 Use of Margins on the Patrol Frigate Design

One of the areas most susceptible to criticism in the Patrol Frigate design is the adjustment of margins from previous design practices. Margins were examined in every area of ship design and were reduced from previous design practices in many areas, including design margins, service life margins, structural margins, electrical power growth margins, and future growth margins.

A margin is defined as "an allowance for weight at a specific location in a ship, made in a weight estimate by the naval architect to cover the inherent lack of precision in initial weight estimates and the unknown additions that will take place in the life of the ship".(23) Margins are similarly applied to other design quantities, such as space, power, and manning.(2)

The margin should reflect the degree of confidence in the weight estimates, the firmness of the design, and anticipated contingencies. A policy of minimum growth margins was established for the Patrol Frigate during conceptual design. This policy resulted from OPNAV guidance to maintain discipline on those factors which contribute to ship growth.(47) Table 3.10 shows the normal margins for a combatant ship and the margins selected for the Patrol Frigate. These reduced margins appear to have been based on two assumptions:



1) the PF was defined at the end of conceptual design to the degree of detail not previously seen before the end of preliminary design, and therefore fewer design uncertainties existed and a careful control of the design could minimize growth.

2) the Chief of Naval Operations eliminated the future characteristics change margin, implying that any new combat system would not increase the weight of the ship. Therefore, there was little need to make allowances for growth after the ship was built. This philosophy carried over into the evaluation of electrical and structural growth margins.

The imposition of constraints by the Chief of Naval Operations should have led to a re-evaluation of the design and builder's margins. The design was no longer firm, and there was no longer a high degree of confidence in the weight estimates. The uncertainties of designing in a new environment should have led to a restoration of the normal preliminary and ship system design margin.

The accommodations margin was reduced from 10% to 5%. This reduction can be justified by the depth of the manning study that was conducted during conceptual design. With the imposition of an absolute limit of 185 accommodations in the PF, the number of accommodations became fixed and the margin ceased to have any meaning.(58)



TABLE 3.10

COMPARISON OF PATROL FRIGATE AND NORMAL MARGINS (47)

<u>MARGIN</u>	<u>NORMAL</u>	<u>PF</u>	<u>BASED ON</u>
Preliminary and Ship System Design	3%	1.5%	Light ship
Detail Design	4%	4%	Light ship*
Building Margin	1%	1%	Light ship*
Contract Modification	1.25%	1%	Light ship
Government Furnished Material	<u>.75%</u>	<u>.5%</u>	Light ship
TOTAL	10%	8%	
Service Life	5%	75 tons (22%)	Full load
KG rise	.5 ft.	.25 ft.	
Future Characteristics Changes	100 tons	none	
Accommodations	10%	5%	

\*Light ship minus 600 tons fixed weights for PF.



Future characteristics change margin is controlled by the Chief of Naval Operations and is used for specific ship improvements and modernization. The service life margin allows for "creeping growth and updating of the ship throughout its active life. The service life margin is used to update and improve ship systems, structures, equipment, and accommodations".(23) At the end of conceptual design, the service life margin was selected as 75 tons, 95 tons below the normal 5% margin for a ship of this type. In detail design 25 tons of the service life margin was allocated to the ship's fin stabilizer systems. One-third of the limited service life margin had been used before the PF keel was laid for a change which should have been charged to future characteristics change.

The reduction in service life margin and the elimination of a margin for future characteristics changes run contrary to the lessons of past ship designs. Extensive weapons system modernization of the DE-1052 class was started before the last ship in the class was delivered to the fleet. The DD-963 class has significant space and weight reserved for future growth and modernization. Leopold points out the distinction between platform life and weapon system life. The life span of a ship hull is approximately 25 years, while the life span of a weapon system is approximately 7-10 years. Past destroyer-type ships have changed payloads two or three times.(8) In this aspect the design of the PF seems to ignore the lessons of the past.





Structural stress margins were reduced because "little future displacement growth is planned".(42) Normally the calculated primary stress is limited to 1.0 tsi (ton per square inch) less than the design primary stress to account for increased stresses due to future displacement growth. The intended stress margin in the PF was to be 0.75 tsi; however, the actual stress margin slipped to 0.50 tsi late in the design due to changes in the ship's weight distribution.(47)

Electrical growth margins were imposed in a manner different from previous designs. The applicable Bureau of Ships Ship Design Division Technical Practices Manual criteria for determining the number and kilowatt rating of ship service generators are:

- 1) A minimum of three generators.

- 2) In the event of derangement of one ship service generator, the remaining ship service generators will carry the functional load (defined as major ship operating load).

- 3) A future load growth margin of 30-40% shall be applied to the functional loads of surface combatant ships other than aircraft carriers.(22)

The Technical Practices Manual also states that no emergency generators are required on ships with diesel driven ship service generators.



The required growth margin was only selectively applied to the Patrol Frigate in power categories 500, 600, and 900: Interior Communications, Control, and Ship Electronics, Ordnance Systems, and 400 Hertz systems. The controlling load is the cruise load at 1927 KW without growth. With the limited growth margins added, the cruise load is 2035 KW.(38)

Four 750 KW diesel generators were originally recommended for the PF electric plant. The electric power plant was changed to three 1000 KW generators to save weight, space, and cost. With three 1000 KW diesel generators the PF could not supply functional load with one ship service generator out of commission after an electrical power growth of less than four percent.

Criterion (2) above was met when the 250 KW emergency diesel was included in the design, but this generator was removed during the weight and stability improvement program late in contract design. A comparison of the PF growth margin with that of other ships is shown in Table 3-11.

The problem of inadequate electrical growth margins was settled with the addition of a fourth ship service diesel generator during detail design.

The detail design and builders margin was not applied to total light ship displacement as in previous designs. 600 tons was considered fixed and not likely to grow during detail design and ship construction, and therefore was not



TABLE 3.11

## POWER GENERATION CAPABILITIES AND MARGINS (10)

SHIP	SHIP SERVICE GENERATORS INSTALLED	EACH GENERATOR RATING KW	FUNCTIONAL LOAD KW	NUMBER GENERATOR FOR CRUISE LOAD
------	--	--------------------------------	-----------------------	---

DE-1040	4	500	956	2
DEG-1	4	500	931	2
DE-1052	4	750	1172	2
DDG-FY67	4	1500	2402	2
PF-109	3*	1000	1927	2
DD-963	3	2000	2271	2

SHIP	DESIGN CRUISE MARGIN	FUNCTIONAL KW + MARGIN	NUMBER GENERATORS FOR CRUISE AFTER MARGIN ADDED
------	----------------------------	---------------------------	---

DE-1040	20%--177KW	1134	3
DEG-1	20%--169KW	1100	3
DE-1052	30%--338KW	1510	3
DDG-FY67	30%--631KW	3033	3
PF-109	5.6%--108KW*	2035	3
DD-963	45%--1022KW	3293	2

\*Contract Design



subject to a growth margin. While this may be a reasonable assumption, it is a departure from past practice and the percentage value of the margins should be adjusted accordingly.

In summary, the margins on the PF were reduced in all areas where these reductions could be justified. This effect is difficult to quantify, but is estimated where possible in Tables A-1 through A-7. The total estimated effect is approximately 240 tons, of which 50 tons includes the fourth diesel generator which was added in the detail design. The total effect of the reduced design and builders' margins will be shown after the PF is completed by a comparison of the estimated contract design weight with the displacement as of the inclining experiment. The reduction in service life and future characteristics change margins will be shown by ship growth after commissioning and by the ability to modernize the Patrol Frigate later in the ship's lifetime. The Patrol Frigate experience with the electrical growth margins (ship service generator selection) and with the future growth margins (ship stabilizers) indicate that the assumptions made in reducing margins may not be valid. The topic of margin determination requires additional study.





### 3.4.3 Impact of Personnel on the PF Design

In recent years the problems of personnel retention and the all-volunteer Navy have brought increased emphasis on habitability and working conditions in naval ship designs. The design of the Patrol Frigate is no exception. Although the PF is austere in many areas, the ship is very comfortable for the men who man her.

In order to reach the desired standard of habitability without severely impacting on the ship's major military characteristics, a program of reduced manning was instituted. Reduced manning started in the conceptual design phase with an emphasis on the cross-utilization of personnel; that is, having men work outside of their area of specialty. This philosophy reduced the required complement from 253 men to 213 men, a 16% reduction.(47) The second step in manpower reduction came with the imposition of an accommodations constraint by the Chief of Naval Operations as discussed in Chapter 2.3. The reduction in accommodations to 185 men resulted in another 13% reduction in manning.

The attention to manning has resulted in several new and unique features that contributed to the complexity of the Patrol Frigate arrangement design. A discussion of these features follows.(39)

The crew living spaces are grouped together in several large complexes rather than numerous small spaces. This arrangement improves the utilization of space and reduces



the requirements for supporting distributive systems such as accesses, air-conditioning and ventilation, and communications systems.

The four-element living concept was introduced with the Patrol Frigate. Separate areas are provided for berthing, dressing, sanitation, and recreation/lounge facilities.

The central galley complex coupled with a provisions and ammunition elevator and dumb-waiter dictated that the wardroom, crew's mess, CPO mess, scullery, and provisions storerooms be arranged adjacent to (either horizontally or vertically) the galley. The overall location of those mess-related spaces was governed by the location of the elevator.

A central office complex was designed to improve personnel utilization and to obtain economies in facilities, total space, and departmental coordination. This concept affected the internal arrangements in that one large office area was required as opposed to many small offices scattered throughout the ship. The central office complex is somewhat less than austere, as it consumes approximately the same space as dispersed offices utilized for the same functions, and it includes a junior officers' work area and a conference room.(35) The conference room and junior officers' work area were added to provide additional work and meeting areas outside the wardroom living area. This luxury seems



excessive in view of the large space allocated to the wardroom area and the austere nature of the Patrol Frigate design.

Passageways are provided throughout the ship so that personnel traffic avoids berthing areas and other functional areas. In keeping with the concept of maintenance by replacement, passageways and accesses have been provided to remove major equipment for shore-based maintenance. The effect of the large passageways on the area available for other ship functions can be seen in Figure 3.5.

In Appendix A, it is shown that each man required an average of 3.28 tons of outfit, furnishings, and personnel related load and an average of 604 cubic feet of personnel related space on the Patrol Frigate. The per man contribution to space and weight on the PF is almost as great as that on the DD-963, a ship with over twice the displacement of the PF. (Figure 3.8) It is obvious that the habitability features on the PF escaped from the requirements to minimize cost and weight.

#### 3.3.4 Propulsion Plant Selection

As shown in Section 3.3, the propulsion plant density (Group two weight per SHP) is lower in the PF than for other U.S. single shaft destroyers. Gas turbine propulsion was selected because of weight and volume advantages over steam and diesel propulsion. These same advantages would probably



have resulted in the selection of a gas turbine propulsion plant even if the PF were not an austere ship. The propulsion plant selected by the Chief of Naval Operations at the end of concept exploration included a cruise turbine, but this turbine was deleted from the ship design early in preliminary design because its advantages were small compared to the space and weight required.

Four hundred tons were saved through the selection of a single screw power plant. From a vulnerability standpoint, a twin screw power plant has little distinct advantage over the single screw plant in a small ship where separate propulsion spaces are not provided for each shaft. (47) For the given speed requirements, it is apparent that a single screw plant would probably have been selected even if the PF had not been an austere design.

The selection of a single shaft gas turbine propulsion plant influenced other decisions, including the requirement for "take-home" capability (auxiliary propulsion system), and the need for a source of auxiliary heat (auxiliary boiler or waste heat system).

The major decisions of gas turbine prime mover and single shaft propulsion are not included in the calculation of the effect of design-to-cost because it is not clear that these decisions would have been different if design-to-cost did not exist. Other engineering plant decisions made in the effort to meet the design goals are included.





#### 3.4.5 Effect of Payload on Design-to-Cost

The decision made during conceptual design to depart from the practice of buying only systems of U.S. design allowed the selection of lightweight weapons systems. Approximately 18 tons in direct weight were saved by the selection of the Italian Oto Melara 76MM gun instead of the closest U.S. alternative, the 5"/54 lightweight gun, and the Dutch Mk 87 gun fire control system instead of the heavier Mk 86 system.

The single decision which resulted in the largest decrease in displacement during FBL and PABL was the May 1972 decision to change the ship's characteristics. The AN/SQS-23 (PAIR) sonar was replaced by a lightweight AN/SQS-505 type sonar and a second LAMPS helicopter was added. Deletion of the weight reservation for the TACTLASS sonar resulted in another large weight savings.

A large portion of the weight and cost savings resulted from the transfer of combat system functions to the LAMPS helicopter. This step results in a decrease in follow ship acquisition cost, because the cost of the helicopter is not considered part of the follow ship cost. The helicopter is purchased as part of the Navy budget, however, so the cost to the Navy should be considered.

Most of payload cost is not under the control of the ship design team at the Naval Ship Engineering Center. Although NAVSEC is charged with keeping cost and weight



below a stated goal, combat systems items amounting to 30-40% of ship costs are beyond the control of NAVSEC. (34)

#### 3.4.6 Inverse Design-to-Cost

Inverse design-to-cost refers to decisions which caused the ship to increase in displacement and therefore ran contrary to the austere philosophy of the PF design. Table 3.12 lists inverse design-to-cost decisions under NAVSEC control. The total effect on the ship design is small, and the primary contributor is the increased size of the passageways. The wide passageways resulted from a tradeoff between volume and accessibility/removability of equipment associated with a cost saving maintenance program. (58,59) The wide passageways can be considered as a cost of reduced manning, which generated the maintenance by replacement philosophy.

Two decisions which were not under the control of NAVSEC contributed to an increase in space and weight of the Patrol Frigate. The habitability standards were not reduced. The direct space and weight effect of reducing habitability standards to the levels of the DE-1052 class for a 185 man crew could be a savings of 87 tons displacement.

Pollution control standards resulted in a large increase in tankage because of the requirement to have a clean ballast system and a sewage system. These large normally empty tanks contributed to the stability problems



TABLE 3.12

INVERSE DESIGN-TO-COST

## UNDER NAVSEC CONTROL

- 61. Enlarge office complex - to provide for junior officer work area and conference room
- 62. Athletic gear storeroom -
- 63. Passageway access design - to allow maintenance by replacement and ease of underway replenishment
- 64. Ability to ballast with fuel tanks - back-up for clean ballast system
- 65. Hard mounting of turbine modules
- 66. Installation of forward bulwark - for better seakeeping characteristics

## NOT UNDER NAVSEC CONTROL

- 67. Habitability standards - standards of living approved by OPNAV

## Pollution Control

- 68. Environmental Control - incinerator and sewage system
- 69. Oily waste holding tank -
- 70. Clean ballast system -
- 71. Close in weapons system - change in payload
- 72. Helo hauldown and traversing system



discussed briefly in Section 3.2. The requirement for including environmental protection systems in naval ships is implied in Executive Order 11507 of 4 February 1971 and Public Law 91-224. Although the adherence to environmental pollution requirements causes an increase in the space and weight devoted to non-mission oriented systems, higher directives leave no choice for the ship designer.

With the exception of the space and weight caused by the increase in habitability and environmental protection systems, very few other design decisions were made which increased the space and weight of the Patrol Frigate.

#### 3.4.7 Limitations of the Analysis

The analysis presented here is limited by the quality of the data and the desire to draw a quantitative conclusion from many qualitative as well as quantitative decisions. Many of the decisions presented as austerity items can also be justified from other criteria, performance, effectiveness, or sound engineering judgement. However, throughout the design of the Patrol Frigate low cost and low weight were given a very high priority in tradeoff analyses.

The recorded change requests reflect only part of the savings in cost and weight attributed to design-to-cost as they only indicate areas in which the Change Control Board actually reviewed design options. Other areas of growth were potentially present but not proposed because of a knowledge of the PF design philosophy.





The second order effects of increased displacement are discussed in a very limited manner. An increase in ship size requires a larger endurance fuel load, more electrical power, and more auxiliary services, further compounding the increase in displacement. Appendix A shows a sample calculation of the increase in endurance fuel required for main propulsion. While the absolute numbers do not accurately reflect the Patrol Frigate, the marginal cost, or fuel ratio, does give a reasonable approximation of one of the secondary effects of the increased displacement. It can be assumed that the increase in propulsive power required to maintain design speed in the enlarged PF can be kept small through an adjustment of the speed/length ratio ( $V/\sqrt{L}$ ).

Table 3.13 shows the design ratios used in the calculation of the effect of design-to-cost. These ratios were derived from the PF/PABL weight statement and from the PF Contract Plan Booklet. These ratios are lower than some of the thumb rules developed from other naval ship designs. For example, C. Graham estimates that the personnel weight ratio is about five tons per man.(10) The DG-AEGIS feasibility studies show a range of 3.9 to 6.5 tons per man personnel weight ratio. The combined space and weight ratio used in this paper equates to about three tons per man. Graham's estimates include more second order effects than the ratios used in this paper. The more conservative ratios are used here.



TABLE 3.13  
PATROL FRIGATE DESIGN RATIOS

<u>RATIO</u>	<u>DEFINED AS</u>	
Fuel Ratio	$\frac{\text{Tons endurance fuel}}{\text{Ton increase in displacement}}$	0.129
Personnel Ratios		
Direct Weight	defined	1.03 ton/man
Indirect Weight	in	2.25 ton/man
Total Effect	Appendix A	3.38 ton/man
Personnel Volume	$\frac{\text{Space Group 2}}{\text{Complement}}$	604 cu.ft/man
Indirect Weight		
Hull Structure	$\frac{\text{Group 1 weight}}{\text{Total Volume}}$	5.37 lb/cu.ft
Electrical	$\frac{\text{Group 3 weight}}{\text{Total Volume}}$	.67 lb/ct.ft
Auxiliary	$\frac{\text{Group 5 Weight}}{\text{Total Volume}}$	1.67 lb/cu.ft
Outfit	$\frac{\text{Group 6 (not related to personnel)}}{\text{Total Volume}}$	.63 lb/cu.ft
Total indirect (excluding fuel)		8.34 lb/cu.ft or .0037 ton/cu.ft



It is assumed that the errors in assignment of design-to-cost influence on design decisions are offset by the conservative method of calculating design-to-cost effects. The influence of the austere philosophy on the tradeoffs proposed to the Change Control Board should be emphasized. However, there is no means to quantify this influence.

This analysis has concentrated its efforts on displacement because weight is an easily calculated quantity. However, the reason for the design-to-cost philosophy is to decrease the cost of ships to the Navy. Within limits low weight equates to low cost. Ship cost estimating programs use the ship work breakdown structure weights to calculate part of the cost of a ship. Many ship costs cannot be accurately estimated any other way. However, on a ship design where both weight and cost are both highly constrained, guidance must be given as to which one should be the controlling parameter. In the PF design cost was the controlling factor. Tradeoff studies were conducted to select the steel to be used in the hull structure. The use of high tensile steel decreases the displacement, but increases the cost of the ship. Mild steel was selected for PF hull structure because of the lower cost. (54)

It is reasonable to discuss design-to-cost in terms of displacement, but the naval architect and ship design engineer must remain aware that the real goal is cost reduction.



#### 3.4.8 Interpretation

Table 3.9 summarizes the calculated effect of the design-to-cost philosophy on the Patrol Frigate. If the Patrol Frigate had not been designed in an austere cost and weight-conscious atmosphere, the ship would probably have displaced over 4500 tons. Without an austere philosophy in the Office of the Chief of Naval Operations, the ship might have had additional weapon systems, especially in the area of anti-submarine warfare, such as ASROC and the AN/SQS-26 series sonar system, and additional speed requirements which could have increased the displacement above 5000 tons.

Figure 3.12 shows graphically the effect of design-to-cost. The PF without the austere design-to-cost philosophy, as calculated in this thesis and shown as squares on this graph, continues but moderates the trend of increasing ship size. The present trend, extended to the commissioning date of the first Patrol Frigate, shows that the latest escort ship might have displaced 6000 tons if restraint had not been shown by those involved in planning for the Patrol Frigate. The analysis in this thesis is considered to be conservative as explained in Section 3.4.7, and therefore provides a lower bound on the effect of design-to-cost.





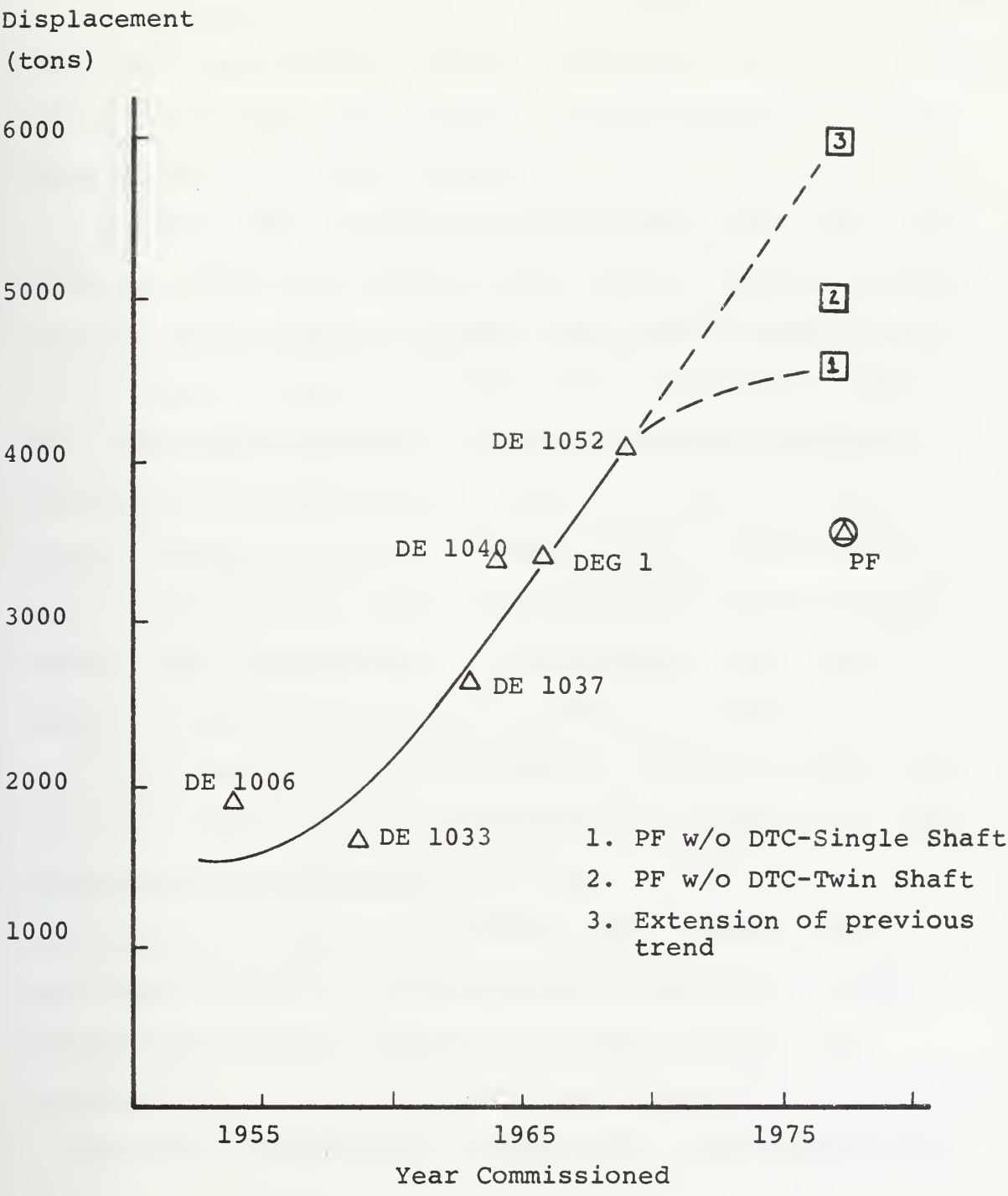


Figure 3.12. Effect of Design-to-Cost



A more accurate analysis, which accounted for the second and higher order effects and the intangible quantities which cannot be measured, would show an unconstrained PF to displace between 4600 and 6000 tons.

The five areas discussed in Sections 3.4.2 - 3.4.6 are primarily under the control of the Chief of Naval Operations. The ship design manager presents the viable alternatives to the CNO, but the decision rests with the customer. The CNO's decisions on payload, propulsion system, manning policies, and margins account for 730 of the 1020 tons "saved" through the design-to-cost efforts. This means that the ship design agent has very little flexibility in reducing ship displacement. As the NAVSEC ship design manager for the Patrol Frigate said; the PF experience ". . . indicates that a 4% reduction in ship's weight is about all that can be reasonably expected (excluding costly concepts like an aluminum hull, etc.). Thus any attempt to set displacement goals for austere destroyer-type ships more than 4% below a good conventional estimate of that ship's displacement according to normal practice is unreasonable. . . Any further weight reductions would have to come out of electronics, habitability, and performance".

(37)



While there are limitations to this analysis, there are two basic conclusions that can be drawn from this section:

1) The ship design community can design a small, combatant ship through the rigorous enforcement of a low cost and weight philosophy of ship design. The trend to ever-increasing size of naval ships is not irreversible.

2) In order for a small ship design to be successful, the customer, the Chief of Naval Operations, must be willing to sacrifice performance in order to achieve cost reductions. Although the design agent has some control over the size of the ship, it is the requirements of the customer which will determine the size of the delivered ship. It is the duty of the naval ship designer to ensure that those men who make the performance/cost tradeoff decisions are fully aware of the implications of their decisions.

There is a continuing debate as to whether or not the Navy should build austere ships. The issues involved with this debate are beyond the scope of this thesis. In an effort to place some of these issues in proper perspective, however, the basic performance characteristics of the Patrol Frigate are compared with the DE-1052 class Ocean Escort in Section 3.6. Chapter IV discusses design-to-cost since the PF and presents some questions as to the future of this design method.



### 3.5 Performance of the Patrol Frigate

Analysis of the performance of the Patrol Frigate is best left to the operations analyst and the ship operator, However, some general statements can be made to put the performance characteristics of this ship in perspective with recent destroyer designs, specifically the DE-1052 class.

Table 3.14 compares the characteristics of the Patrol Frigate with the DE-1052. The two ships are similar in size, but the PF is designed primarily for anti-air warfare and the DE-1052 is designed primarily for anti-submarine warfare. The PF was designed to operate in conjunction with an ASW ship carrying an advanced sonar system with an ASROC (Anti-Submarine ROCket) launcher. In this manner the PF can help form a team to defend against air, surface, and submarine attacks.(28) The DE-1052's primary mission is anti-submarine warfare.

The PF's primary weapons system is the MK 13 Mod 4 launcher that can fire the Standard anti-aircraft missile and the Harpoon anti-ship missile. The PF carries two LAMPS (Light Airborne Multi-Purpose System) helicopters and ship launched torpedoes for anti-submarine warfare.

The Patrol Frigate's sustained speed is 28 knots, approximately one knot faster than the DE-1040 and DE-1052 class ships.





TABLE 3.14

COMPARISON OF PATROL FRIGATE WITH DE-1052 CLASS SHIPS (45)

	<u>DE-1052 Class</u>	<u>Patrol Frigate</u>
Full Load Displacement	4100 tons	3600 tons
Internal Volume	481,000 cubic ft.	517,000 cubic ft.
Length Overall	438 ft.	445 ft.
Length on Waterline		408 ft.
Guns	1 5"/54 dual purpose	1 76MM dual purpose 1 CIWS*
Missile Launchers	1 multiple Sea Sparrow AA	1 Combined Standard/ Harpoon Launcher AAW and SUW
Anti-Submarine Warfare	1 helicopter 4 torpedo tubes 1 ASROC launcher	2 helicopters 6 torpedo tubes
Engines	Steam Turbines	Gas Turbines
Horsepower	35,000	40,000
Propeller Shafts	1	1
Speed	27+ knots	28+ knots
Complement	245-283**	185

\*Space and Weight for Close-In Weapon System (CIWS)

\*\*Depending upon staff and helicopter requirements



As compared by Kehoe, the PF has better seakeeping characteristics than the DE-1052 because the PF does not have a large sonar dome and because of the PF's high freeboard.(7) With roll stabilization installed, the PF will have as good or better seakeeping performance than most U.S. and U.S.S.R. ships of her approximate displacement.

A superficial look at the performance of the PF indicates that the ship has not suffered from being a design-to-cost ship in the areas of speed and seakeeping. The Patrol Frigate weapon systems appear to be adequate for her designated missions; however, the ship is susceptible to many of the criticisms originally levied against the DE-1052 class, as in the controversy that followed the publication of "A United States Navy for the Future" in the U.S. Naval Institute Proceedings.(19) These were the requirements of the operating forces, and so this was the way the ship was designed. The true test of the PF will come after the ships operate at sea.

### 3.6 Summary of Chapter III Conclusions

1. The PF weight history shows a continuing battle to overcome growth in ship system weights. The fact that ship weights continued to grow, even into detail design, indicates that early weight estimates were optimistically low. The errors became apparent as the ship grew in definition in the progression of design stages.



2. The PF has the same internal volume, but a displacement of 500 tons less than the DE-1052 class. This was accomplished through a shift to less dense components (weapons, propulsion, and personnel) than previous ship designs. The wider passageways and the tanks for control of environmental pollution also decrease the density of the PF.

3. Allocation of weight by function in the PF is very similar to the DEG-1 class with the exception of a lower payload weight in the PF. The lower payload weight is a result of the use of a lightweight gun and a smaller sonar on the PF.

4. Payload density and engineering plant density have both decreased primarily as a result of technological advances. Space and weight per man devoted to personnel have increased with increasing standards of habitability, but the percent of the ship devoted to personnel has not changed appreciably because of the emphasis on reduced manning. There have been no significant weight savings from structural innovations on the PF.

5. Margins were reduced to decrease displacement wherever reductions could be justified. Subsequent experience in detail design indicates that some of these margins should not have been reduced or adjusted. The concept of margins as applied to naval ship design requires further evaluation.



6. If the Patrol Frigate had not been designed in an austere, cost and weight conscious atmosphere whe might have displaced 4500 tons or more. A twin shaft PF would probably have displaced over 4900 tons.

7. High standards of habitability and environmental protection have added about 150 tons to the PF's displacement.

8. Design-to-cost did result in a significantly smaller ship than might have been expected under previous design philosophies. The trend to ever increasing ship size is not irreversible.

9. In order for an austere ship design to be successful, the customer, the Chief of Naval Operations, must be willing to sacrifice performance in order to achieve the desired cost reductions. Although the design agent has some control over the size of the ship, it is the requirements of the customer which will determine the size of the delivered ship.

10. A judgment of the mission effectiveness of the PF will have to wait for operational evaluation under fleet conditions. The PF appears to be capable of carrying out the missions selected for her by the Chief of Naval Operations, but the ship is susceptible to many of the criticisms of the DE-1052 Class. The viability of the high-low concept and the usefullness of an austere escort is a very controversial subject, beyond the scope of this paper.





## CHAPTER IV

### DESIGN-TO-COST SINCE THE PF

In addition to the PF, the Navy has designed four ships under the design-to-cost philosophy, the sea control ship (SCS), the anti-aircraft destroyer (DG-AEGIS), a constrained aircraft carrier (CVX), and a fleet oiler (AO-177 class).

The sea control ship was envisioned as a very austere platform from which helicopters and VSTOL aircraft could operate. This ship was designed with a manning and a cost constraint; however, the cost constraint was set too loosely and the design was completed within the constraints without severely taxing the design engineers. Contract design was completed, but the detailed design was never funded. The primary reason given for not funding the SCS was the lack of an aircraft to use the platform; but because of the lack of capabilities in the austere design, the SCS was considered by many to be inadequate to perform the sea control mission. This ship has been described as a "floating box".(52)

The DG-AEGIS was envisioned as an austere platform which would have the anti-air defense capabilities of the AEGIS system. This ship was constrained in displacement and cost. The DG-AEGIS had an original cost target of 100 million dollars. Feasibility studies showed that the desired ship could not be built for less than 125 million, and that became the cost goal



for preliminary design. Very detailed and well documented cost-performance tradeoff studies were conducted in the DG preliminary design phase. The methodology is described in the Leopole, Jons, and Drewey paper.(8) The DG completed preliminary design with a cost estimate of approximately 135 million dollars. Because of the growing cost and the changing philosophy of the operating forces (see below), the DG did not go into contract design.

Constrained aircraft carrier designs have been started under the titles of CV, CVX, CVL, and continuing CV. Although feasibility studies have been conducted for a carrier with a lead ship cost goal of under 550 million dollars and a tentative conceptual baseline has been completed, the project has never continued into preliminary design.

The AO-177 class was designed as an austere fleet oiler. As a single mission auxiliary, the oiler did not present the same degree of conflict in cost versus performance as is found in combatant ships. The AO-177 class has completed contract design and will be placed into production when funded by Congress.

The required supporting documentation, so carefully laid out in the design methodology, has not been followed in actual practice. The Patrol Frigate Top Level Requirements were not signed until the contract for detailed



design and lead ship construction had been signed. For the PF, the TLR represented a statement of historical fact, not a working document. Top level specifications were not generated for the PF.

The Sea Control Ship was designed without a Top Level Requirements document; no statement of requirements was issued. However, the SCS design package did include a set of Top Level Specifications.

The DG-AEGIS had Top Level Requirements for preliminary design, but the SHAPM did not allocate funds for the generation of a Top Level Specification. The design was dropped before this problem was resolved.(52) The AO-177 class design also had top level requirements, but no top level specifications.

As can be seen from the fate of the constrained ship designs, the concept has not been successfully pursued from design into production in any ship since the Patrol Frigate.

The primary reason for this is the unwillingness of the Navy leadership to accept an austere ship design. Both the DG-AEGIS and the Sea Control designs died because the ships which could be produced within the desired cost range were considered inadequate from a performance viewpoint.

Two recent events have served to emphasize this problem. In August, 1974, Congress passed what is known as the Title Eight Legislation, requiring the Navy to install nuclear propulsion in all new construction strike force ships.



This requirement eliminates all propulsion plant tradeoff studies and removes the propulsion plant design effort from the Naval Ship Engineering Center to the Naval Reactors Division of NAVSEA. The size and weight of a nuclear reactor requires a large hull and a large initial expense, and therefore it does not make sense to constrain severely other areas of the ship design.

The second event is the relief of Admiral Zumwalt by Admiral Holloway as Chief of Naval Operations. Admiral Zumwalt was the originator and chief advocate of the constrained ship design. He was an "old school" destroyerman and believed in small ships. Admiral Holloway is nuclear trained and a former Commanding Officer of the nuclear carrier ENTERPRISE. He has stated on several occasions that the Navy needs more offensively capable surface ships. It is difficult to develop a meaningful design-to-cost dialogue in a ship design which is pre-determined to be nuclear powered and have significant offensive capabilities.

Design-to-cost is not dead. The fiscal climate which provided the impetus for DTC has, if anything, worsened. The decline in total Navy ships predicted in 1970 has taken place with only two large shipbuilding programs in existence, (DD-963 and PF), to rebuild the surface fleet. The need for a larger number of ships to carry out the objectives of national policy still exists. While this need is partially met by the Patrol Frigate (PF) and the





Patrol Hydrofoil (PHM), the force level of the Navy is still at a very low level. The solution proposed by Admiral Rickover in the January 1974 Naval Institute Proceedings to build all nuclear ships is not politically feasible due to the reluctance of the Congress to increase radically annual appropriations for ship acquisition.(17) Although the present philosophy is to build large, nuclear powered, highly capable escort ships, financial realities will force a re-evaluation of priorities and a return to some form of Design-to-Cost.



## CHAPTER V

### CONCLUSIONS AND RECOMMENDATIONS

#### 5.1 Summary of Conclusions

This thesis has examined the design-to-cost philosophy as implemented in the design of the Patrol Frigate. The significant conclusions which have been drawn from this analysis are as follows:

1) The design-to-cost philosophy departs from previous design philosophies in two areas:

- a) Acquisition costs (defined in a very narrow sense) and not life cycle costs are optimized.
- b) Ship design is not performance optimized.

Performance must be balanced against cost.

2) The design-to-cost philosophy included the imposition of constraints on full load displacement, follow ship acquisition cost, and accommodations (maximum manning). The initial values of these constraints were based more on the feeling of what was possible than on sound engineering analysis.

3) Although the Patrol Frigate is a design-to-cost ship, ship cost was not directly controlled as a design parameter. System and subsystem cost tradeoffs were made on the basis of marginal cost factors and cost deltas.

4) The Naval Ship Engineering Center (NAVSEC) used a complex budget system to control the ship design. The designers and engineers had not previously worked with a



design budget, and the effort was only partially successful. The most significant element in the control of the PF weight and cost was the existence of a strong Change Control Board. This board emphasized low cost and low weight in all phases of the ship design effort and was able to control the growth of the design. The most successful tool for design control was the arrangement drawings and the space budget.

5) The PF weight history shows a continuing battle to overcome growth in ship system weight. The fact that ship weights continued to grow, even into detail design, indicates that early weight estimates were optimistically low. The errors became apparent as the ship grew in definition in the progression of design stages.

6) The emphasis on weight control has resulted in the PF being considerably less dense than other destroyers and destroyer escorts. The PF has approximately the same internal volume, but a displacement of 500 tons less than the DE-1052 class. This was accomplished through a shift to less dense components (weapons, propulsion, and personnel) than previous ship designs. The wider passageways and the tanks for control of environmental pollution also decreases the density of the PF.

Payload density and engineering plant density have both decreased, primarily as a result of technological advances. Space and weight per man devoted to personnel



have increased with increasing standards of habitability, but the percent of the ship devoted to personnel has not changed appreciably because of the emphasis on reduced manning. There have been no significant weight savings from structural innovations on the PF.

7) Calculations have shown that if the Patrol Frigate had not been designed in an austere atmosphere, she might have displaced 4500 tons or more. A twin shaft PF would probably have displaced over 4900 tons. These estimates are considered to be conservative.

8) Decisions by the Chief of Naval Operations with regards to payload, personnel, propulsion, and margins resulted in the majority of the weight savings. In order for an austere ship design to be successful, the customer, the Chief of Naval Operations, must be willing to sacrifice performance in order to achieve the desired cost reductions. Although the design agent has some control over the size of the ship, it is the requirements of the customer which will determine the size of the delivered ship.

9) In spite of problems with the implementation of design-to-cost, the displacement and cost of the Patrol Frigate were controlled throughout the preliminary and contract design phases. Design-to-cost did result in a significantly smaller ship than might have been expected under previous design philosophies. That is a significant victory for design-to-cost. The trend to ever-increasing ship size is not irreversible.





10) The future of design-to-cost is clouded by the Title Eight requirements for nuclear propulsion and the desire to increase the offensive power of U.S. Naval ships. Debate over the tradeoff between desired force structure and available resources is continuing. Some form of restraint is necessary if the United States is to build the numbers of ships required to fulfill the nation's defense requirements. Design-to-cost is one method of achieving this restraint.

## 5.2 Recommendations for Further Study

Design-to-cost is a very broad subject. There is a need for continued research into the effect and usefulness of design-to-cost as applied to naval ship design. Some of the areas where further research is desirable include:

1) A more detailed study of the Patrol Frigate should include the second order effects described in this thesis. The approximations made in the calculation of the effect of design-to-cost should be verified.

2) The total effect of design-to-cost should be verified by a redesign of the PF, including those features which are listed as austerity measures as an integral part of the ship design, rather than the cumulative effect used in this paper.

3) This project should be continued through the completion of the detail design and construction of the lead and follow ships. Design-to-cost is only one part of



the problem of acquisition-to-cost. The problem of maintaining control of the ship design after completion of contract design requires additional study.

4) Better marginal cost data should be generated to improve the information used to make ship design tradeoff decisions.

5) A study similar to this one should be conducted on the NAVSEC ship designs completed since the PF. Have these designs benefited from the PF experience? How has design-to-cost affected the other austere designs? Have the austerity philosophy and the more careful design procedures affected ship designs which are not constrained?

6) The relationship between the customer (the CNO) and the designer (NAVSEC) requires further evaluation and definition. A rational method of selecting design constraints should be developed.

7) The use of margins in ship design requires further study.

8) The relationship between cost constraints, displacement constraints, manning constraints, acquisition cost, and life cycle cost requires further study. Is the Navy saving money by concentrating on a reduction in follow ship acquisition cost or is the wrong standard being used? This study should include the effects of aviation components and the shore-based maintenance facilities which are not included in the PF follow ship acquisition cost.



9) A comparison of the design effort required for a design-to-cost ship design with an unconstrained ship design could quantify the cost of the design-to-cost effort. From this study the effort required by design-to-cost could be justified.

10) There is no standard for judging the "goodness" of a ship design or of an acquisition program. A set of standards needs to be developed so that programs can be evaluated on an objective basis.

11) The usefulness of austere warships should be studied very carefully. Are the resulting ships capable of carrying out the missions of the U.S. Navy?

This thesis could not have been completed without the tremendous amount of documentation now available on recent ship designs. That documentation should be used to help make ship design easier and to help design better ships. It is hoped that the effort which was used to accumulate these records is not wasted.



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54. Kerr, George, NAVSEC Deputy Design Manager, DG Ship Design, formerly Systems Engineer, PF Design Project, NAVSEC, personal interview, January 22, 1975.
55. Milano, V.R., Captain, U.S.N., Head, Design Division NAVSEC, formerly PF Design Manager, personal interview, January 22, 1975.
56. Milano, V.R., Captain, U.S.N., personal correspondence, March 25, 1975.
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60. Spaulding, K.B., Jr., NAVSEC Project Management Section, Design Planning and Control, formerly PF Deputy Ship Design Manager, personal interviews, January 22, 1975, and March 25, 1975.
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## APPENDIX A

### CALCULATION OF DESIGN-TO-COST EFFECTS

This Appendix details the calculations used to determine the ratios used in the quantification of the design-to-cost austerity measures and tabulates the impact of these measures as follows:

1. Calculation of endurance fuel ratio
2. Calculation of indirect weight ratios
3. Calculation of personnel ratio

Table A-1. Summary of Calculated Effect of Design-to-Cost

Table A-2. Conceptual Design Austerity Measures

Table A-3. FBL/PABL Engineering Austerity Measures

Table A-4. FBL/PABL Payload Austerity Measures

Table A-5. FBL/PABL Hull Structural Austerity Measures

Table A-6. FBL/PABL Personnel Austerity Measures

Table A-7. Inverse Design-to-Cost Decisions Under NAVSEC Control

Table A-8. Inverse Design-to-Cost Decisions Not Under NAVSEC Control

Table A-9. Austerity Decisions Not Quantified

NOTE: The number in front of each item in Tables A-2 through A-9 refers to the tables in Section 3.2. The starred items indicate those decisions which were reversed in detail design as described in Section 3.2.



## 1. Calculation of Endurance Fuel Ratio

### Assumptions:

Initial displacement: 3500 tons

Endurance Range: 4500 N.M. at 20 kts. (Estimate  
in "Jane's Fighting Ships")

Endurance SHP: 9000

New displacement: 4400

Specific fuel consumption at endurance speed:

0.5 pounds fuel/SHP (typical for  
LM2500 turbine)

No change in auxiliary loads with increased  
displacement.

### Calculations:

Assume  $\frac{\text{SHP}}{\Delta} = \text{constant}$

$$\frac{\text{SHP}}{\Delta} = \frac{9000}{3500} = 2.57$$

$$\text{SHP at new displacement} = \frac{\text{SHP}}{\Delta} \times \Delta = 2.57 \times 4900 = 11,300$$

Endurance fuel at 3500 tons:

$$\text{tons fuel} = \text{SHP} \times \frac{\text{range}}{\text{speed}} \times \text{sfc}$$

$$= (9000 \times \frac{4500}{20} \times .5 \times \frac{1}{2240}) = 568$$

Increase in fuel = 116 tons

$$\text{Fuel Ratio} = \frac{116 \text{ tons fuel}}{900 \text{ tons displacement}} = .129 \text{ tons endurance fuel per ton displacement}$$



NOTE: While the numbers used in the calculation do not accurately represent the PF, the derived ratio provides a good approximation for this analysis.

## 2. Indirect Weight Attributed to Volume Increases

	<u>PF</u>	<u>DE-1052</u>
1. Hull Structure ( $\frac{\text{Group 1}}{\text{Total Volume}}$ )	5.37	6.49
2. Electrical ( $\frac{\text{Group 3}}{\text{Total Volume}}$ )	.67	.56
3. Auxiliary ( $\frac{\text{Group 5}}{\text{Total Volume}}$ )	1.67	1.61
4. Outfit ( $\frac{\text{Non-personnel Gp. 6}}{\text{Total Volume}}$ )	<u>.63</u>	<u>1.06</u>
Total effect	8.34 lb/cu.ft.	9.72 lb/cu.ft.
or	$\frac{.0037}{\text{cu.ft.}}$	$\frac{.0043}{\text{cu.ft.}}$





### 3. Calculation of Personnel Ratios

#### Direct Weight

	<u>PF</u>	<u>DE-1052</u>
Group 6 weight allocated to personnel	120.4	77.1
Officers, crew and effects	21.0	27.1
Provisions and personnel stores	21.5	40.3
Potable water	<u>28.0</u>	<u>36.0</u>
	190.9T	180.5T
Complement	185	245
Direct Weight per man	1.03 $\frac{\text{ton}}{\text{man}}$	.74 $\frac{\text{ton}}{\text{man}}$

#### Indirect Weight

Personnel Volume	111,823	116,538
Volume per man	604 $\frac{\text{ft}^3}{\text{man}}$	476 $\frac{\text{ft}^3}{\text{man}}$
Indirect Weight per unit volume	8.34 $\frac{\text{lb}}{\text{ft}^3}$	9.72 $\frac{\text{lb}}{\text{ft}^3}$
Weight effect of personnel volume	2.25 $\frac{\text{ton}}{\text{man}}$	2.07 $\frac{\text{ton}}{\text{man}}$

Total Personnel Effect  
(Direct and Indirect)

3.28  $\frac{\text{ton}}{\text{man}}$     2.81  $\frac{\text{ton}}{\text{man}}$



TABLE A-1

CALCULATED EFFECT OF DESIGN-TO-COST

Conceptual Design (Table A-2)	343.8
FBL/PABL Engineering (A-3)	294.5
FBL/PABL Payload (A-4)	115.4
FBL/PABL Hull (A-5)	31
FBL/PABL Personnel (A-6)	104.4
Endurance Fuel	<u>130</u>
Total Effect	+1019.1
PF PABL Displacement (12/72)	<u>3540.</u>
PF without Design-to-Cost emphasis	<u>4559.1</u>
Effect of Second Shaft	+ <u>400</u>
Twin Shaft PF without design-to-cost emphasis	<u>4959.1</u>
Effect of Inverse Design-to-cost	
Under NAVSEC Control	- 43.5
Not under NAVSEC Control	- <u>170.9</u>
Total Effect	- 214.4
PABL Displacement	<u>3540.</u>
Possible PF displacement	<u>3326.</u>



TABLE A-2

CONCEPTUAL DESIGN AUSTERITY MEASURES

Austerity Measures	Weight Savings (tons)	Notes
1. Deletion of Future Change Characteristics Margin	100	2
2. Reduction in Service Life Margin	95	2
3. Buy Foreign		
Gun System (76MM Oto Melara vs. 5"/54 LW)	16.1	2
Fire Control System (Mk 87 vs. Mk 86)	1.5	2
4. Cross utilization of personnel decreasing manning from 253 to 213 men (40 men)	131.2	2,3
Total	343.8	

NOTE: An additional 400 tons was saved by selecting single screw vice twin screw (note 2). A twin screw ship has little distinct advantage over a two screw ship in a small combatant and so it is probable that single screw would have been selected even without the emphasis on low weight as long as the speed requirements remain unchanged.



TABLE A-3

FBL/PABL ENGINEERING  
(main propulsion, auxiliary and electrical)  
AUSTERITY MEASURES

Austerity Measures	S A V I N G S			Notes
	Deck Area (sq.ft.)	Volume (cu.ft.)	Weight (tons)	
6. Central Workshop	540			1-25
7. Single ship's boat			13.0	1-33
8. Removal of 2nd anchor chain and windlass			13.5	1-64
8. Removal of 2nd anchor			2.2	1-64
9. Decrease size of AFFF stations	60			1-79
10. Air compressor selection			5.6	1-95
11. Replace 600 HP auxiliary propulsion motor with two 325 HP motors	1174		9.0	1-101
12. Remove milling machine			1.8	1-211
14. Remove oil and water test lab	66		.7	1-213
15. Delete main engine silencers and acoustic treatment			12	1-218
22. Remove emergency diesel, substitute 10KW for 250KW diesel	2000		4.9	1-295
16. Remove one degaussing coil			3.3	1-272
17. Reject additional decon station	20			1-243
18. Remove two fire pumps*			2.1	1-297
19. Elimination of cruise engine			1.25	4





TABLE A-3  
(cont)

Austerity Measures	S A V I N G S			Notes
	Deck Area (sq.ft.)	Volume (cu.ft.)	Weight (tons)	
20. Deletion of Roll Stabilization*			25	4,15
21. Decrease in electrical margins, resulting in one less electrical generator*			50	5,6 7,19
13. Replacement of auxiliary boiler with waste heat system		127	21.3	8
23. New standard for calculating CPP shafting			9.	6,9
Deck area total	3860			
Volume effect of Deck Area		32180		13
Volume Total		32307		
Weight Effect of Volume			119.8	14
Total Weight			294.5	



TABLE A-4

FBL/PABL PAYLOAD AUSTERITY MEASURES

Austerity Measures	S A V I N G S			Notes
	Deck Area (sq.ft.)	Volume (Cu.ft.)	Weight (tons)	
31. Resize due to sonar removal			60	1-113
32. Remove TACTLASS			30	1-114
31. Reduce size of sonar space	192			1-178
37. Deletion of monorail hoist in helo compartment			15	1-273
33. Remove signalman's shelter			2	1-205
39. Remove RPS custodian's office	64			1-305, 12
Total Deck Area	266			
Volume Effect of Deck Area		2261		13
Weight Effect of Volume			8.4	14
Total Weight			115.4	



TABLE A-5

FBL/PABL HULL STRUCTURAL AUSTERITY MEASURES

Austerity Measures	S A V I N G S			Ref.
	Deck Area (sq.ft.)	Volume (Cu.ft.)	Weight (tons)	
37. Remove ECM equipment room on O-2 level			1.0	1-207
38. Replace circular chain lockers with built-in lockers			2.3	1-215
39. Remove deck house front, side bulwarks and fashion plates			1.4	1-206
40. Rearrangement of tanks to save weight			4	1-265
41. Remove unnecessary bulkhead between Mk92 and CIC cooling rooms			.2	1-293
42. Remove longitudinal bulk- head aft*			6.6	1-208
43. Reduced structural margins			15.5	9,10
Total			31	



TABLE A-6

FBL/PABL PERSONNEL AUSTERITY MEASURES

Austerity Measures	S A V I N G S			Ref.
	Deck Area (sq.ft.)	Volume (cu.ft.)	Weight (tons)	
48. CNO decrease in manning			91.8	3,11
49. Reject increase in medical spaces	140			1-29
50. Combined Galley	130			9,12, 18
51. Remove spare furniture from XOSR			.25	1-286
52. Medical treatment room doubles as forward battle dressing station	70			1-240 9
53. No provision Issue Room	50			9,12
Total Deck Area	390			
Volume Effect of Deck Area		3315		13
Weight Effect of Volume			12.3	14
Total Weight			104.4	





TABLE A-7

INVERSE DTC DECISIONS UNDER NAVSEC CONTROL

Decisions	POSSIBLE SAVINGS			Notes
	Deck Area (sq.ft.)	Volume (cu.ft.)	Weight (tons)	
61. Enlarge Office Complex	150			1-162
62. Athletic Gear Storeroom	53			1-251
63. Passageway/Access Design		5169		16,17
64. Ability to Ballast with fuel tanks			5.5	1-63
65. Hardmounting of turbine modules			14	1-74
66. Forward Bulwark			4	1-224
Total Deck Area	203			
Volume Effect of Deck Area		211.5		
Total Deck Area		5380.5		
Weight Effect of Volume			20.0	
Total Weight			43.5	



TABLE A-8

INVERSE DTC DECISIONS NOT UNDER NAVSEC CONTROL

Decisions	POSSIBLE SAVINGS			Notes
	Deck Area (sq.ft.)	Volume (cu.ft.)	Weight (tons)	
67. Habitability (185 men at DE-1052 standards)			87	16
Pollution Control				
68. Environmental Pollution Control			9.86	6
69. Oily Waste Holding Tank		2673		1-245
70. Clean ballast system		10612		20
71. CIWS			9.5	15
72. Helo Hauldown and Traversing System	192		9	15
Total Deck Area	192			
Volume effect of Deck Area		1632		13
Total Volume		14917		
Weight Effect of Volume			55.5	14
Total Weight			170.9	



TABLE A-9

AUSTERITY DECISIONS WHICH ARE NOT QUANTIFIED

	<u>Notes</u>
5. Reduction in Design and Builders Margin	2
24. Simplified Underway Replenishment System	9
25. Inclusion of Helo Fuel as Part of Endurance Fuel and Sliding Endurance Displacement Calculation	9
26. No-Dial Telephone System	9
27. No provision for Pneumatic Tubes for Communications	9
28. Less Severe Noise Requirements than Recent DE's	9
29. No STOPS Treatment of any kind	9
30. Removal of Roll Tank	1-110
34. No Secondary Conning or Lookout Stations	9
44. Extensive use of GRP Topside and in Non-Structural Materials	9
45. Removal of Unnecessary Watertight Hatches	1-281
46. Reduced Helicopter Platform Structural Design Criteria	9
47. No External Inclined Ladders	
54. Unmanned Engine Room with Remote Operation	9



## APPENDIX A

### NOTES

1. Naval Ship Engineering Center, Patrol Frigate Change Request files for FBL, POST-FBL and PABL. Number following 1- refers to change request number.
2. Naval Ship Systems Command, Patrol Escort Concept Exploration Report (U), July 1971.
3. Weight savings for personnel is calculated as:  
3.28 tons per man direct weight; 604 cubic feet of space per man
4. Naval Ship Systems Command, Patrol Frigate Ship Acquisition Plan, June 1973.
5. Naval Ship Engineering Center, Design Decision Presentation Brief, "Electrical Generator Selection", December 10, 1971.
6. Guided Missile Frigate (FFG-7), Weight Report, March, 1975.
7. Personal correspondence with Captain V.R. Milano, USN, NAVSEC, March 24, 1975.
8. Gibbs and Cox, Analysis of a Waste Heat System for Application to the Patrol Frigate, January 30, 1973.
9. Naval Ship Engineering Center, Technical Design History of Patrol Frigate, Rough Draft, January, 1975.
10. Naval Ship Engineering Center, PABL Design History Summary for Structural Design, December 12, 1972.

(This history states that stress margin was decreased from 1.0 tsi to .75 tsi less than the design primary stress because little future displacement growth is planned. The limiting primary stress is 8.5 tsi so this change was assumed to decrease structural weight in groups 100 and 101 by

$$\frac{.25}{8.5} = 2.9\%.$$





11. CNO/VCNO Action Sheet 836-71 of October 18, 1971.
12. Naval Ship Systems Command, DE-1052 Contract Plans, April, 1964.
13. Assumed average deck height of 8.5 feet.
14. Assumed weight effect of 8.34 #/ft<sup>3</sup> enclosed volume from page 131.
15. Naval Ship Engineering Center, Patrol Frigate Top Level Requirements Draft dated November 21, 1974.
16. Naval Ship Engineering Center, Ship Space Classification Data, March, 1970.
17. Assume same percent devoted to passage and access as in DEG-1.
18. Difference between PF pantry and DE-1052 wardroom galley.
19. Telcon with R. Steward, NAVSEC SHAPM Support Manager, April 3, 1975.
20. PF Contract Plans.



## APPENDIX B

### CLASSIFICATION OF COST ESTIMATES

This appendix defines the classification of cost estimates as used by the U. S. Navy and set forth in OPNAVINST 7720.2, Classification of SCN Cost Estimates.(26)

#### 1. Class A - Detailed Cost Estimate

An extensive cost estimate prepared to validate an end cost estimate; for determination of a "fair and reasonable" price for comparison to contractors prices; but primarily for contract negotiation purposes. It is always prepared in the post-budget process and generally prior to a bid opening or scheduled negotiation and fixed price incentive or cost plus type contracts. This level of cost estimate requires contract plans and specifications and a detailed contract design weight estimate as inputs from the design process.

The cost and economic inputs are primarily unit material and man-hour cost estimating relationships developed to the NAVSHIPS Consolidated Index of Materials breakdown (3 digit level) of costs, vendor quotations for all major material items and a thorough analysis of the competitiveness of the market, expected labor and profit rates, escalation, etc.

Due to the extensiveness of the estimate, requiring in excess of five weeks of development and calculation of data, this type of estimate is only prepared when conditions so warrant such a level of detail.



## 2. Class B - Bid Evaluation Estimate

An estimate prepared to validate the "reasonableness" of cost estimates received from contractors or government shipyards. Prepared immediately prior to a bid opening or upon receipt of an initial cost estimate from a naval shipyard.

The scope is similar to a Class A Cost Estimate except that the estimate is not as detailed. Unlike the Class A Detailed Cost Estimate, material quotations are not necessarily obtained from industry; and the cost estimating relationships used reflect a higher degree of aggregation.

## 3. Class C - Budget Quality Estimate

These are considered to be the highest level of cost estimates attainable in the planning, programming and budgeting process since the more extensive Class A and Class B estimates are considered post-budget estimates. A Class C estimate is the recommended level for estimates of cost to be used in the budget submission especially at the Congressional level, preferably for the NAVCOMPT and OSD/BOB submissions and whenever feasible for the Program Objective estimates for the current budget year.

SCB Approved Characteristics with appended electronic requirement and weapon installation plans are a requirement. In addition, special items not necessarily included in the SCB approved characteristics, such as, extent of automation,



hull materials, shock level, silencing requirements, selected system engineering requirements and other unique or special items should be known.

For conversion estimates to conform to this classification, the detailed scope of the complete ship rearrangements and relocations as well as a survey of the repair status; time since previous overhaul; outstanding ship alterations; history of previous rehabilitation costs on similar ship type conversions, etc. must be available.

Equipment, allowances and other costs obtained outside of NAVSHIPS must be documented by official memoranda. The electronics, ordnance, propulsion, etc., should be sufficiently defined and developed technologically to eliminate any inordinately high developmental costs. If items of uncertainty do exist, appropriate growth factors must be included and the cost estimate classification additionally noted. The cost estimating relationships (CER) used in the estimate should be based on reliable design and cost data (accepted weight estimate and contract bid information or naval shipyard return cost data be available).

If the design, technical or cost information is lacking credibility or in the opinion of the cost estimator significant information is questionable, the cost estimate is to be classified at some lower level.





#### 4. Class D - Feasibility Estimate

An estimate of a lower quality than a Class C estimate due to an insufficiency in the design, procurement or cost information primarily the result of a need for an estimate before such information can be further developed to justify a C classification. Such early estimates are usually exploratory in nature and are prepared to perform trade-offs and cost effectiveness analysis, to establish notional ship characteristics and for costing the Program Objectives in the out-years where there is an absence of sufficient design development.

Generally, the primary design input for a Class D estimate will be SCB Feasibility and Cost Study Characteristics (single sheet) as opposed to the SCB Approved Characteristics included in Class C estimates. Cost estimates derived solely by a plus and minus technique from a higher quality estimate or from a repeat design where SCB guidance on the project deletes or adds characteristics which have a potential impact or significantly altering the design configuration are considered to be a feasibility estimate due to the lack of sufficient design development.

Since cost estimates, as developed for a ship type under Contract Definition, are almost always subject to change upon receipt of the contractor's design package, the design information supporting this category of cost estimates can be considered to be only preliminary in nature; and the cost estimate should, therefore, be included in this classification.



## 5. Class E - Computer Estimate

An estimating process when cost and design information is developed by use of a computer model which grossly determines ship specifications from a given set of input characteristics. In general, the output cost and design information is calculated from estimating relationships through a series of equations while payload type items such as electronics, ordnance, etc., are costed by a shopping list technique within the model.

Present applications of this type of cost estimate are for parametric cost studies, where relative costs and not absolute costs are primarily considered, and for estimates of ships which are in the conceptual design stage.

## 6. Class F - "Ball Park" Estimate

Quick cost estimates are those prepared in the absence of the minimum design and cost information package and are based on gross approximate parameters. Typically, estimates are generally calculated by merely escalating to current dollars an empirical cost for a similar ship and adding factors for expected changes in design, accounting procedures or other economic considerations.



## APPENDIX C

### ABBREVIATIONS AND ACRONYMS

AAW	Anti-Air Warfare
AFFF	Aqueous Film Forming Foam (fire fighting system)
ASROC	Anti-Submarine Rocket
ASW	Anti-Submarine Warfare
CFE	Contractor Furnished Equipment
CGN	Nuclear Guided Missile Cruiser
CNO	Chief of Naval Operations
DCP	Development Concept Paper
DD	Destroyer
DDG	Guided Missile Destroyer
DDS	Design Data Sheet
DE	Destroyer Escort (Now FF)
DEG	Guided Missile Destroyer Escort (Now FFG)
DG-AEGIS	AEGIS-Guided Missile Weapon System-equipped Destroyer
DLGN	Nuclear Guided Missile Frigate (Now CGN)
DOD	Department of Defense
DSARC	Defense Systems Acquisition Review Council
FBL	Functional Baseline
FF	Frigate
FFG	Guided Missile Frigate
FSABL	Follow Ship Allocated Baseline
GFE	Government Furnished Equipment
GFI	Government Furnished Information



LAMPS	Light Airborne Multipurpose Systems (Shipboard helicopter system)
LSABL	Lead Ship Allocated Baseline
NAVMAT	Naval Material Command
NAVSEA	Naval Sea Systems Command
NAVSEC	Naval Ship Engineering Center
NAVSHIPS	Naval Ship Systems Command, now a part of NAVSEA
OPNAV	Office of the Chief of Naval Operations
PABL	Preliminary Allocated Baseline
PF	Patrol Frigate (Now FFG)
PMS-399	Patrol Frigate Designated Project Manager
SCS	Sea Control Ship
SECNAV	Secretary of the Navy
SHAPM	Ship Acquisition Project Manager
TLR	Top Level Requirements
TLS	Top Level Specifications
UNREP	Underway Replenishment
VERTREP	Vertical Replenishment









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